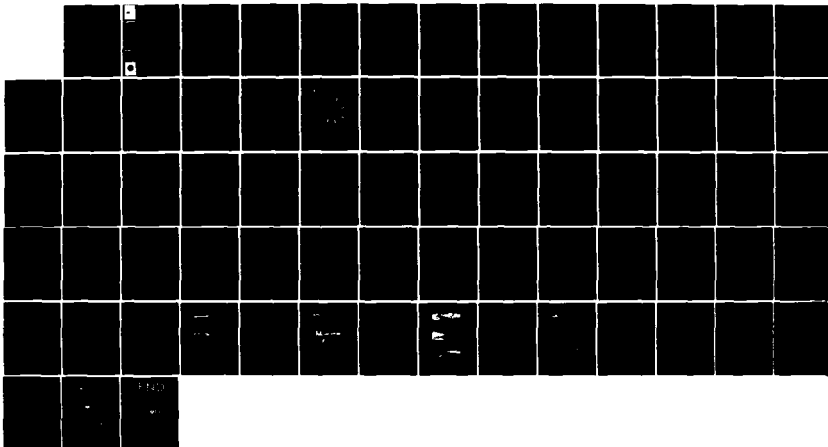BEACH CHANGES AT MISQUAMICUT BEACH RHODE ISLAND
1962-1973(U) COASTAL ENGINEERING RESEARCH CENTER
VICKSBURG MS R W MORTON ET AL. NOV 84 CERC-MP-84-12

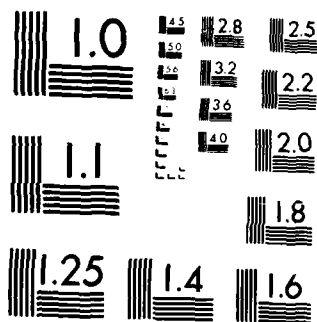MICROCOPY RESOLUTION TEST CHART
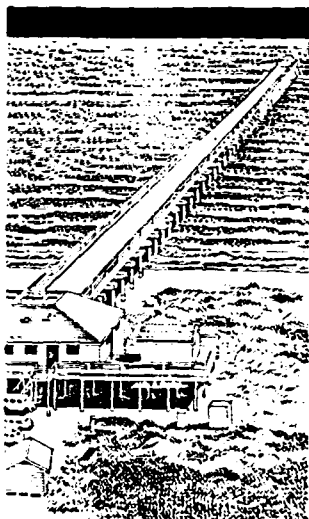
NATIONAL BUREAU OF STANDARDS 1963 A

AD-A150 233

US Army Corps
of Engineers

BEACH CHANGES AT MISQUAMICUT BEACH RHODE ISLAND, 1962-1973

by

Robert W. Morton, W. F. Bohlen,
David G. Aubrey, Martin C. Miller

Science Applications, Inc.
202 Thames Street
Newport, Rhode Island 02840

DTIC FILE COPY

TIC
ELECTE
FEB 1 4 1985

November 1984
Final Report

A

85 02 04 044

Destroy this report when no longer needed. Do not return
it to the originator.

The findings in this report are not to be construed as an official
Department of the Army position unless so designated
by other authorized documents.

The contents of this report are not to be used for
advertising, publication, or promotional purposes.
Citation of trade names does not constitute an
official endorsement or approval of the use of
such commercial products.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ᴹᴾ Miscellaneous Paper CERC-84-12	2. GOVT ACCESSION NO. AD-A150 233	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* BEACH CHANGES AT MISQUAMICUT BEACH, RHODE ISLAND, 1962-1973		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert W. Morton, W. F. Bohlen, David G. Aubrey, Martin C. Miller		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Science Applications, Inc. 202 Thames Street Newport, Rhode Island 02840		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS DEPARTMENT OF THE ARMY US Army Corps of Engineers Washington, DC 20314-1000		12. REPORT DATE November 1984
		13. NUMBER OF PAGES 66
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*) US Army Engineer Waterways Experiment Station Coastal Engineering Research Center PO Box 631, Vicksburg, Mississippi 39180-0631		15. SECURITY CLASS. *(of this report)* Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*
Beaches--Rhode Island (LC)
Beach erosion (LC)
Coast changes (LC)
Misquamicut Beach (R.I.) (LC)
Shore-line--Rhode Island (LC)

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

    Beach profile data were collected at profile lines on Misquamicut Beach between November 1962 and June 1973. The data were examined for temporal and spatial patterns and variability along the beach face, as well as to identify and assess the forces which influence beach behavior. Misquamicut represents a typical barrier beach. It is sheltered from all directions except the south and southeast with the wave climate modified by Fisher's Island, Long Island, and Block Island. Nearshore bathymetry and a submarine trough in Block Island

(Continued)

DD ᶠᵒᴿᴹ 1473 EDITION OF 1 NOV 65 IS OBSOLETE

20. ABSTRACT (Continued).

Sound also modify the wave pattern and intensity. The focusing of energy
varies depending on wave direction, but is generally most intense in the
center of the beach.

   Regression analyses on above mean sea level volume versus time indicate
a net accretional trend on the beach. Profile line 1, located against the west
jetty at Weekapaug Inlet, displayed the highest average accretion rate, 80
cubic meters per meter per year. This accretional trend may result in part
from longshore transport into the area. The jetties at Weekapaug Inlet act as
a barrier presenting longshore transport to the east. Two shallow nearshore
shoals paralleling the beach further prevent sediment loss. They appear to
trap beach material during storm events and erosional cycles and return it
during accretional cycles. The nourishment of the beach through sand fill
along the recreational beach front may also significantly contribute to
accretion.

   There appears to be a seasonal pattern to erosion accretion cycles on
Misquamicut Beach. In general, erosion is accelerated from late autumn to
early spring, principally as a result of winter storm events, while accretion
occurs from late spring to early fall. However, nonseasonal storm events
frequently interrupt and obscure this pattern. The beach responds in a
similar manner to most storms regardless of the direction of the storm track.
The average above mean sea level volume changes attributable to storms range
from 5 to 10 cubic meters per meter of beach length, which is small in com-
parison to open ocean beaches (as those studied on Cape Cod) where changes
were frequently on the order of 50 cubic meters per meter.

PREFACE

This report is one of a series describing the results of the US Army Coastal Engineering Research Center (CERC) Beach Evaluation Program. One aspect of the program, and the subject of this report, is to provide basic engineering information on changes in shoreline position, as attained from long-term beach survey projects. The 11-year study of Misquamicut Beach, Rhode Island, was begun in November 1962 and continued through June 1973. The work was carried out under the CERC beach behavior and restoration program.

The report was prepared by Robert W. Morton (Principal Investigator), Science Applications, Inc. (SAI), Newport, Rhode Island; W. F. Bohlen, Marine Science Institute, University of Connecticut, Groton, Connecticut; David G. Aubrey, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts; and Martin C. Miller, Exxon Corp. (formerly with SAI, Raleigh, North Carolina). Eigenfunction analysis programs were written by D. Aubrey, while the remaining analysis software was provided by Joseph Karpen (SAI, Raleigh).

The authors acknowledge and appreciate the review and comments provided by the personnel of CERC. On 1 July 1983 CERC was transferred to the US Army Engineer Waterways Experiment Station (WES). A. E. DeWall was the contract monitor for the Evaluation Program, under the general supervision of R. M. Sorenson, Chief, Coastal Processes and Structures Branch, CERC. Chief of CERC during the publication of this report was Dr. Robert W. Whalin.

Commander and Director of WES during the publication of this report was COL Robert C. Lee, CE. Technical Director was Mr. F. R. Brown.

Accession For

NTIS GRA&I

DTIC TAB

Unannounced

Justification

Dist.

Avail

Dist

1

CONTENTS

---

* Appendixes B-G are on file at the US Army Engineer Waterways Experiment
  Station and are available for loan.

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

---

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

BEACH CHANGES AT MISQUAMICUT BEACH, RHODE ISLAND, 1962-1973

I. INTRODUCTION

1. Background.

This document is one of a series of reports providing analysis and interpretation of beach profile data obtained between 1962 and 1973 by the U.S. Army Coastal Engineering Research Center (CERC) as part of the Beach Evaluation Program (BEP) (formerly known as the Pilot Program for Improving Coastal Storm Warnings or the Storm Warning Program). The BEP was initiated after the Great East Coast Storm of March 1962 in order to observe variations on typical beaches in response to waves and tides of significant intensity and duration. Twelve beaches in the region hardest-hit by that storm (Massachusetts to North Carolina) are under study in this program. Other applications of the BEP include generating a predictive model of beach erosion (Galvin, 1969) and providing basic engineering information for the planning and design of protective structures or remedial strategies for stabilizing and maintaining beaches (Everts, 1973).

This report presents an analysis of the beach profile data obtained from surveys of seven profile lines across Misquamicut Beach on the south coast of Rhode Island (Fig. 1). Replicate measurements of vertical beach profiles were made between November 1962 and June 1973 by the New England Division of the US Army Corps of Engineers. All profile line locations are documented, and measurements of elevation above sea level are presented for each measurement period. An analysis of these data is provided which evaluates the changes in beach elevation, sand volume, and shoreline position resulting from the wave regime, water level, and storm events that occurred during the period of the surveys. In addition, previous work in the area is reviewed to examine long term trends in waves, winds, and tides and to develop a framework in which to interpret beach changes.

Variability in the shape of the beach was evaluated with standard methods utilized at CERC as well as empirical eigenfunction techniques. Of particular note were changes in beach elevation, slope, volume, and mean sea level (MSL) intercept resulting from particular storm events. Changes were evaluated over three time scales:
    (a) Long-term changes that occur over periods of a year or longer;
    (b) seasonal changes occurring over a typical three-month period; and
    (c) short-term changes resulting from specific storms or events between surveys.

2. Previous Work.

The beaches forming the south coast of Rhode Island were periodically surveyed from 1961 through 1972 as part of a continuing investigation of local coastal geology conducted by scientists from the University of Rhode Island (URI) (McMaster, 1973). One of the profile lines occupied during these
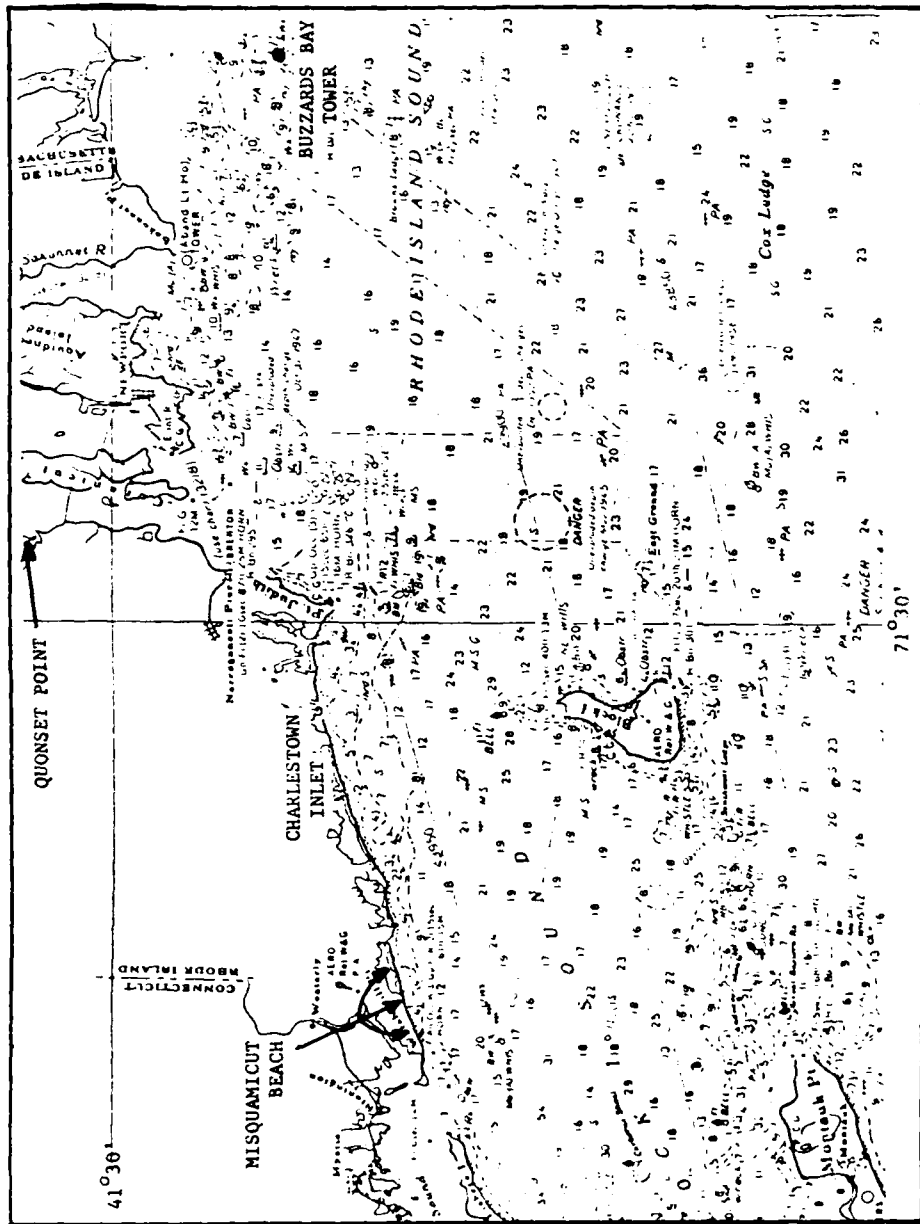
5

Figure 1. Index map of south coast of Rhode Island

surveys is located along Misquamicut Beach at Weekapaug. The results of these surveys indicate that Misquamicut is the most stable of all southern Rhode Island beaches which as a whole change very slowly with time. All beaches had little seasonal response, but did show impact of local storm events. In addition to this long-term work, a number of site-specific studies have been conducted by URI to detail processes affecting a particular section of south coast beaches. Several of these latter studies include the Misquamicut area: for example, McMaster (1960), who utilized mineralogy to examine sand movement; Dillon (1970), who related changes in sea level to barrier migration; Regan (1976), who evaluated long-term shoreline changes through comparison of aerial photographs; Coddington (1976), who related beach changes to dynamic processes; Gautie (1977), who studied the geomorphology of Rhode Island beaches in terms of erosion and accretion characteristics; and Hagstrom (1978), who conducted grain size analysis of foreshore sands.

The proposed development of the Charlestown Naval Facility at Charlestown, R.I., as a nuclear powerplant created a requirement for environmental data in this region and some work was done offshore, primarily by Raytheon Corporation (1975) and the University of Rhode Island. However, since the plant was not approved, complete analysis of these data was not fully realized (U.S. Army, NED, 1957).

II. THE STUDY AREA

1. Geology and Geomorphology.

Misquamicut Beach is a low-lying barrier beach located near the western limit of the south coast of Rhode Island (Fig. 1). The beach, which extends a distance of approximately 8.5 kilometers east from Watch Hill Point to Weekapaug Point (Fig. 2) separates the offshore waters of Block Island Sound from those of several bordering coastal ponds. Winnapaug Pond, the largest of these embayments, has free communication with Block Island Sound via a breechway cut through the beach. Although originally present as a small creek, this inlet is now maintained in position by riprap armoring of the channel and a pair of stone jetties. The east jetty was constructed in 1900 and the west jetty in 1954 by the State of Rhode Island. The remaining ponds (Mickill, Maschaug, and Little Maschaug) are effectively isolated from Block Island Sound.

The dune line, backshore, and foreshore of Misquamicut Beach are composed primarily of fine to medium sands interspersed with occasional areas of coarser sands and gravel on the upper foreshore. The bulk of this material is glacial in origin and was supplied primarily by ice advance and meltwater runoff over the Charlestown moraine which borders the inshore limit of the coastal ponds. Erosion and weathering of local till headlands such as Weekapaug Point represent a secondary source. Sediment profile data obtained at several locations along the beach indicate the presence of organic rich materials. This suggests that the beach initially formed well seaward of its present position and migrated progressively shoreward as sea level advanced (Dillon, 1970).

Misquamicut Beach varies in width from about 100 meters along the western limits to slightly more than 150 meters adjacent to Weekapaug Inlet. Alongshore, the seaward margin displays several prominent irregularities
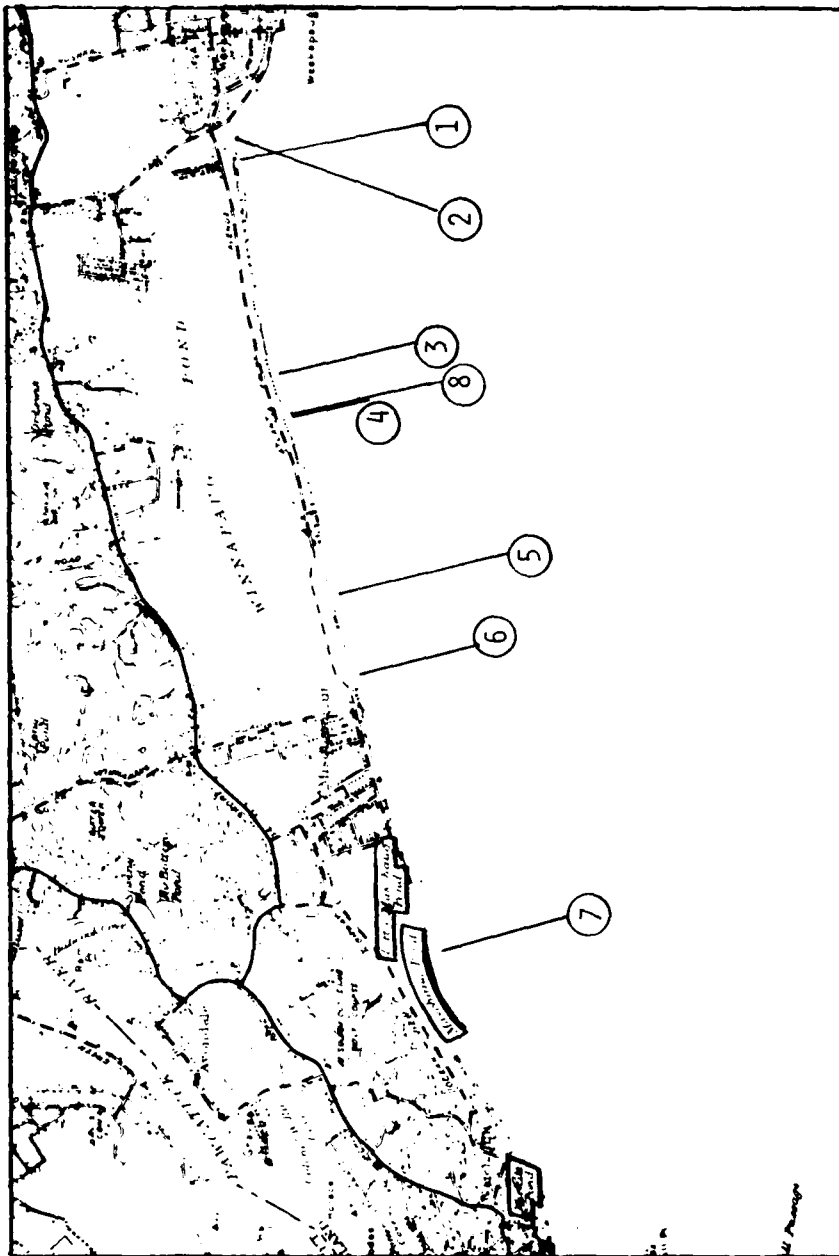
Figure 2. Beach profile locations, Misquamicut Beach study area

causing the planform to depart significantly from a simple curvilinear shape. These irregularities appear to be randomly spaced and there is no evidence of spatial periodicity. Maximum dune elevations decrease progressively from east to west, ranging from a maximum of about 6 meters above MSL adjacent to the inlet to less than 3 meters near Watch Hill. Beach face slopes in the area remain essentially constant. Foreshore slope values range from approximately 1:15 during the summer to 1:20 and 1:25 during the winter.

Higher up the beach face, in the area between mean high water and the base of the dune line, slopes display a higher degree of spatial and temporal variability. Along the western limits of the beach, in the area extending about 3 kilometers east from Watch Hill Point, summer conditions favor the formation of a shoreward-sloping (convex up) backshore. With increasing energy conditions during the winter, the berm progressively erodes until the upper beach merges uniformly with the intertidal zone. Farther east along the beach, there is no well developed summer berm and slopes grade uniformly away from the base of the dune line at approximately 1:30 during the summer to between 1:20 to 1:25 in the winter.

Local studies of sea level indicate a consistent, long-term rise in the Misquamicut area (Hicks and Crosby, 1974). Although of secondary importance compared to other forces, sea level changes are an important consideration when assessing long term trends in profile development. The closest locations reporting monthly sea levels for a significant period of time are New London, Connecticut, and Newport, Rhode Island, with records dating from 1930 to 1975 (Permanent Service for Mean Sea Level, 1977). Regression analysis of New London data shows a mean yearly sea level rise of 2.7 millimeters per year with a coefficient of determination, r^2, of 0.67, while Newport has a sea level rise of 3.0 millimeters per year, with an r^2 of 0.78. These increments of sea level rise, though small, impose a documentable pressure on the development and evolution of barrier beaches along the New England coast. The Newport data display significant short term variability and during the period 1960-65 favored a slight decrease in relative sea level stand. After 1965 this trend reversed and by 1970 relative sea level was approximately 2.7 centimeters above the level observed in 1960. The cause of these short period fluctuations is not known.

The importance of sea level changes can be documented through a comparison of MSL intercept on two beaches with different slopes. In the absence of profile readjustments and a beach slope of 3°, a 10-year sea level rise of 3 centimeters vertically corresponds to a horizontal transgression of 0.6 meter. A 1° slope with a 10-year sea level rise of 3 cm vertically corresponds to a horizontal transgression of 1.7 meters.

Development along Misquamicut Beach is confined to the region extending from Little Maschaug Pond east to Weekapaug Inlet (Fig. 2). Several types of structures have been constructed over the past 40 years including private recreational housing, a large State-owned bathhouse, and numerous small commercial establishments. There is also a Rhode Island State Park located approximately 2.5 miles west of the inlet which extends across 3200 feet of the beach. Many of the structures have been placed directly on the dune line. In addition, a paved roadway extends along the back of the dune line providing access for the entire area. Historically, both the roadway and shore-front structures have experienced significant storm damage. The

hurricane of 1938 resulted in extensive loss of life in the Misquamicut area and destroyed virtually all the housing along the beach (Allen, 1976). Some was reconstructed only to be destroyed again by Hurricane Carol in 1954 (URI, 1955). Since that time, the absence of a major hurricane has encouraged an acceleration of beach-front construction particularly along the eastern limits of the beach. With this density and the combination of relatively low elevation and preferential housing placement along the dune line, the developed area of Misquamicut Beach must be considered to have a high potential for significant economic and physical loss during any major hurricane or storm event.

2. Offshore Bathymetry.

The sea floor immediately adjacent to Misquamicut Beach (Fig. 2) consists primarily of fine to medium sands with occasional areas of glacial till. These materials are actively eroded and transported by local wind waves and tidal currents resulting in varied and dynamic bathymetric contours (Fig. 3). Average depth contours begin essentially shore-parallel in the area adjacent to Watch Hill Point. Proceeding eastward, contours become progressively more irregular in orientation leading to a well-defined shoal in the area offshore of Maschaug and Little Maschaug Ponds. The irregularity associated with this feature extends for about 1.15 kilometers along the beach. Continuing eastward, contours again become shore-parallel and essentially maintain this orientation until a second major shoal is encountered at a distance of about 4 kilometers east of Watch Hill Point. This feature, associated with a till deposit, is extremely variable in outline and extends alongshore for a distance of approximately 2.4 kilometers modifying the incident wave field and resultant beach sediment transport. Beyond this shoal contours regain a parallel orientation to the beach which continues to Weekapaug Point.

On a smaller scale, the sea floor immediately offshore of the beach is deformed into a series of bed forms with bathymetry displaying several scales of spatial periodicity. Side-scan sonar and diver surveys of the area indicate that these bed forms consist primarily of ripples, megaripples, and sand waves (Morang and McMaster, 1980). The sand waves are generally small amplitude, shore parallel features with wavelengths of about 10 to 15 meters. They are observed out to depths of about 8 meters. Recent surveys suggest, however, that these observed sand waves may in fact be artifacts of the side scan recording procedure (Cook, 1981). Megaripples in the area occurred as shore perpendicular features extending offshore for 200 to 400 meters. The occurrence and distribution of the megaripples varies in time and may be sensitive to the energy conditions incident along the beach.

Beyond the immediate beach area, contours are moderately smooth and regular (Fig. 4). Within Block Island Sound, the average depth is about 30 meters with significant variations noted in the vicinity of the submarine ridge extending between Montauk Point and Block Island. This feature, including Montauk Point and Block Island provides significant sheltering for the south coast of Rhode Island and serves to substantially modify the character of the wave field propagating shoreward from the adjacent continental shelf. The ridge is cut from north to south by the relict drainage pattern associated with the Block Channel which extends south across the shelf to the Block Canyon. Within Block Island Sound, this drainage pattern consists of two submerged valleys with maximum depths of 55 meters
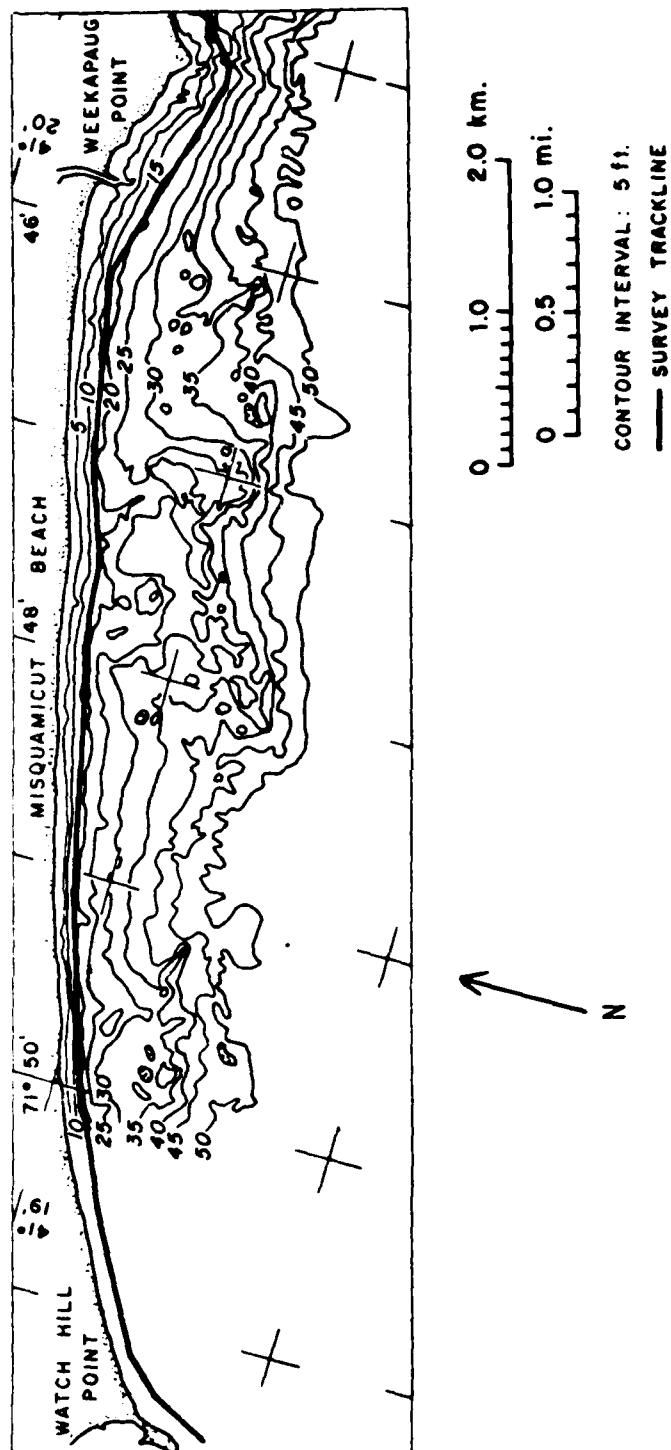
10

Figure 3. Nearshore bathymetry adjacent to Misquamicut Beach
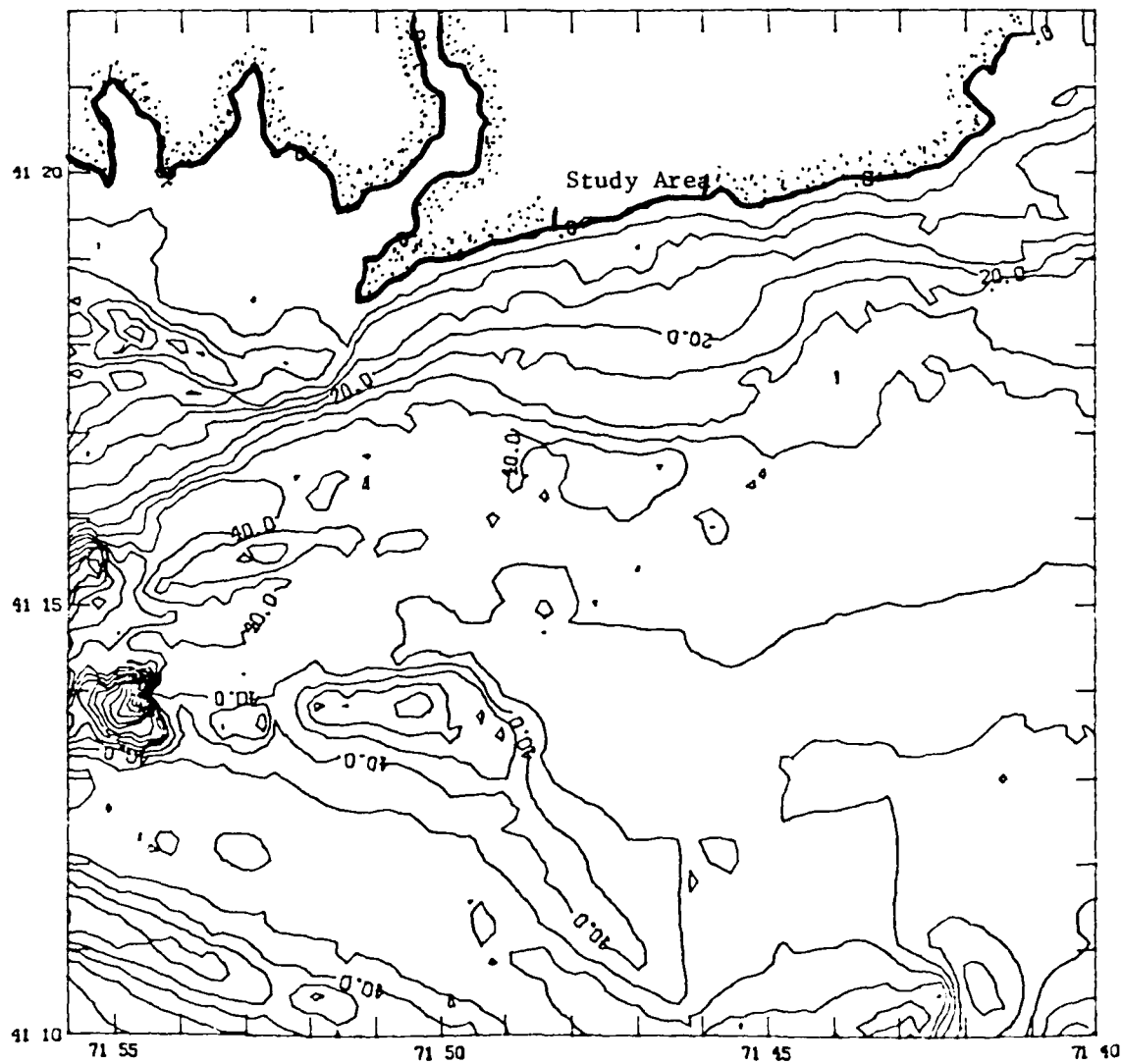(Morang and McMaster, 1980)

11

Figure 4. Detailed bathymetry of seafloor adjacent to
Misquamicut Beach (contour interval is 5 meters)

(Savard, 1966). The northernmost valley, which is apparent in the bathymetry in Fig. 4, directly affects the the waves incident on Misquamicut Beach.

3. **Littoral Processes.**

Sediment movement along and across Misquamicut Beach is the result of a variety of factors including winds, surface waves, tidal currents, and man's activities. These factors act individually and collectively to affect the routes and rates of sediment transport and the ultimate shape of the beach.

a. *Tides.* Tides within Block Island Sound are dominantly semidiurnal with a mean range of 0.78 meter and a spring range of 0.96 meter. Associated tidal currents in the area just offshore of Misquamicut Beach display a maximum velocity of 60 centimeters per second (1.2 knots) during the westward flood and 35 centimeters per second (0.7 knot) during the eastward ebb. Data from the Charlestown study indicate a net westward drift during the warm months and an eastward drift that is extremely variable during the winter months (Raytheon Corporation, 1979).

Average tidal conditions can be significantly perturbed during aperiodic storm events. Reviews of the time-series data at the Newport tidal station indicate that annual average storm conditions can be expected to produce an increase in high water elevations of about 0.6 meter while the 100-year storm conditions would produce a surge of about 3 meters.

b. *Winds.* Local winds are seasonal in character with southwesterlies favored during the summer and northwesterlies in the winter (Fig. 5). Aperiodic storm events can occur throughout the year but are most usually confined to the late fall, winter, and early spring period. Peak winds during these events generally come from either the easterly or westerly sectors. Winds rich in northerly or southerly components usually represent transient conditions occurring during the passage of the storm center or associated frontal system.

c. *Surface Waves.* The wave field within Block Island Sound is primarily the result of onshore propagation of waves generated along the adjacent continental shelf. Sheltering by Long Island and Block Island effectively precludes significant local wave generation and also filters the onshore propagating wave field. As a result, maximum wave energy along Misquamicut Beach is associated with storm systems favoring wave propagation from the east and south-southeasterly directions. Wave observations local to Misquamicut are limited; however, visual observations obtained sporadically at Watch Hill Light Station from January 1968 through December 1975 indicate that waves propagating from these directions can reach a maximum height of approximately 3 meters with periods exceeding 12 seconds.

An indication of the frequency of occurrence of such waves can be obtained using in situ data obtained by a bottom-mounted recording gage located about 8 kilometers (5 miles) east of Weekapaug Point just offshore of the Charlestown Inlet in water depths of about 8 meters. (Fig. 1). These data indicate that over the year deployment period from April 1974 to April 1975, during which time 243 days of data were obtained, significant wave height exceeded 1.5 meters for about 2 percent of the time (Raytheon Corp., 1975). For the majority of the time (92.1 percent), significant wave
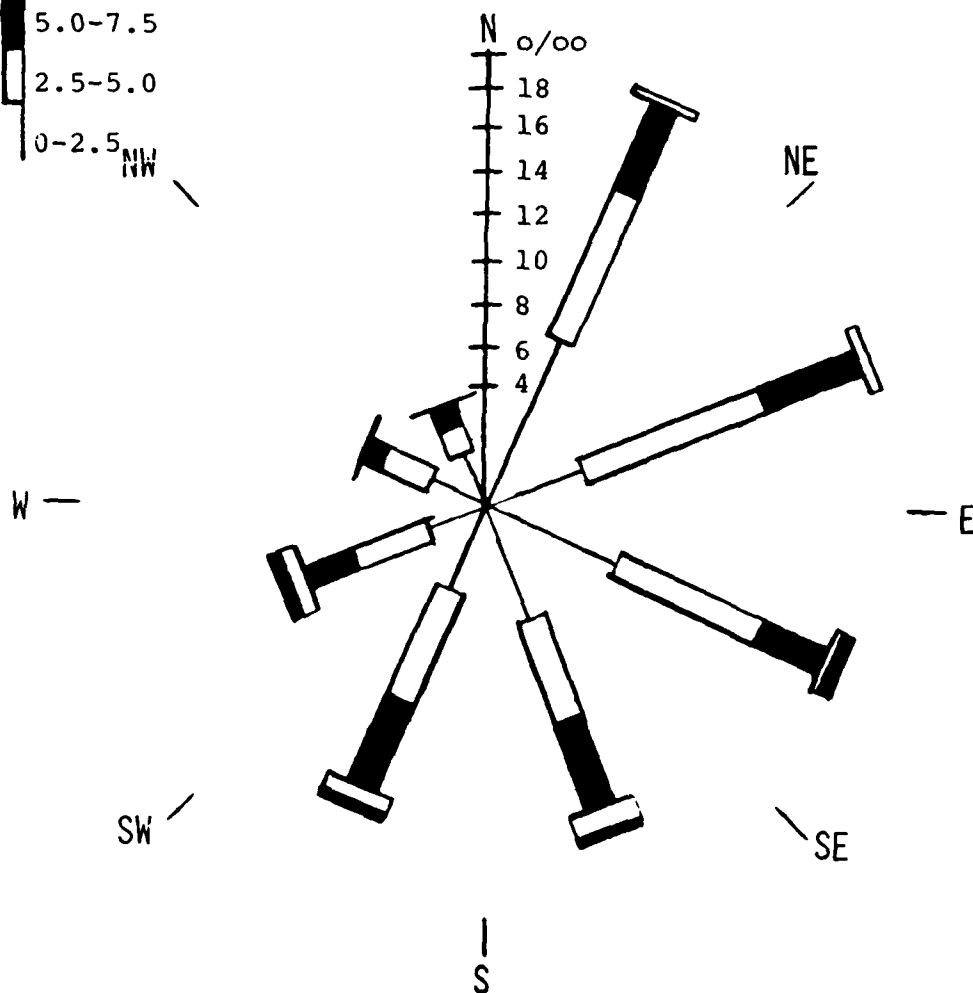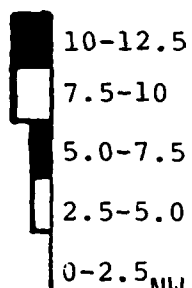
13

Figure 5. Wind rose of frequency percentage of winds by
speed and direction measured at Quonset Point, 1 January
1963–31 December 1972

height was less than 1 meter. Overall these conditions appear representative of a low to moderate energy coastal regime.

d. <u>Man's Activities</u>. Sediment distribution along Misquamicut Beach has also been affected by man's activities. These disturbances have been primarily confined to the eastern half of the beach fronting the area of maximum development. Observations of the area indicate that fill has been occasionally placed along the upper beach and that extensive areas of the dune line and bordering beach have been mechanically graded. The extent of these operations cannot be simply quantified. Before the establishment of the State of Rhode Island Coastal Resources Management Council in 1971, it appears to have been standard practice to annually grade the beach during the spring months to repair winter storm damage. Detailed records on the extent and location of these operations, however, were not maintained.

In conjunction with beach grading, state and local officials have indicated that several schemes intended to stabilize the beach have been tested over the past 30 years. Again, details concerning the form and location of these operations are lacking. Possibly the most ambitious of these projects involved the placement of wrecked cars in an attempt to stabilize the beachfront adjoining one of the larger hotels near the middle of the study area. This operation was apparently conducted after the 1954 hurricane and the cars still appear from time to time during periods of intense erosion activity (Westerly Sun, 1966, 1972). Although additional details concerning this and other similar operations are not well documented, it is apparent that the eastern section of the beach has been and continues to be heavily impacted by man's activities.

III.   METHODS

1.   <u>Profile Lines & Monumentation</u>.

a.   <u>Profile Line Location</u>.   Seven profile lines were monitored on Misquamicut Beach during the BEP survey period (Fig. 2). Profile lines 2,5,6 and 7 (established as part of the Storm Warning Program) were reoccupied at the beginning of this study. Lines 1 and 3 were added in April 1963; and line 4 was established in August 1964. Profile line 4 was relocated about 4.5 meters eastward in July 1967 because of a local construction project and was redesignated line 8. The profile lines are concentrated on the eastern part of the beach within 5 kilometers of Weekapaug Inlet. The longshore spacing between profile lines is not uniform. Although the mean spacing between profiles is 800 meters, the spacing varies from 253 meters to a maximum of 1535 meters (Table 1).

15

Table 1

Summary of Profile Lines and Surveys

Profile line	Distance between adjacent profile monuments (m)	Survey Period		Total Survey
		First Reading	Last Reading	
1	153.46	8 Apr. 1963	8 June 1973	132
2	1535.83	7 Nov. 1962	7 June 1973	141
3	261.12	8 Apr. 1963	16 Apr. 1973	131
4*	4.58	20 Aug. 1964	1 June 1967	34
8	1193.41	5 July 1967	8 June 1973	76
5	430.03	7 Nov. 1962	8 June 1973	139
6	1259.78	7 Nov. 1962	8 June 1973	138
7		7 Nov. 1962	8 June 1973	137

* Relocated 4.58 m E July 1967, redesignated line 8.

In 1973, concrete monuments with brass plate markers were installed at the landward end of the profile lines to facilitate rapid relocation. The profile monuments were surveyed by the New England Division to third-order accuracy referred to the Rhode Island state plane coordinate system. Horizontal control was maintained for each monument in relation to fixed cultural landmarks such as roadways, buildings, telephone poles, etc. Detailed monumentation plots showing the position of each profile line are presented in Appendix A.

The surveying crews used the level and tape technique to measure the profile lines. A reference elevation was established at a fixed object such as the top of a log barricade, the foot spike on a telephone pole, or nail markers driven into the roadway. The survey was conducted seaward, along the predetermined azimuth which was perpendicular to the shoreline. Measurements were made at 15-meter intervals with each reading rounded to the nearest foot (30 centimeters) in the horizontal, and tenth of a foot (3 centimeters) in the vertical plane.

b. Survey Frequency. Profile measurements were begun on a monthly basis at lines 2,5,6 and 7 in November 1962 and continued through 1973. From the winter of 1967 continuing through 1970, the lines were often surveyed on a semi-monthly or weekly basis in the winter and early spring to better measure the impact of winter storm events. The only gap in profile measurements occurred in the summer of 1968, otherwise, all seasons between 1963 and spring 1973 are represented. The distribution of seasonal measurements by month and

year is shown in Figures 6 and 7, respectively. Profile data are presented in tabulated form in Appendix B.*

2. Analytical Procedures.

a. Profile Line Analysis. Profile line surveys were analyzed by CERC, and computer plots were generated for changes in above MSL volume relative to the long-term mean (App. C), changes in MSL shoreline intercept from the original survey (App. D), and profile envelopes (App. E). The origin of the coo.dinate system, to which all surveys are referred, is the monument location in the horizontal plane and MSL in the vertical.

The cross-sectional area under each profile was calculated as defined by three lines: (1) a vertical line projected from the landwardmost distance common to all surveys on a given profile line, (2) a horizontal line at the MSL elevation, and (3) the surveyed profile. The calculation was accomplished by summing the area of 30.5-centimeter horizontal slices through the area bounded by the profile from the highest elevation to MSL. The area change was then computed by subtracting the current measured profile area from the long-term mean cross-sectional area (Figure 8). Note that the change in area (and volume) were referred to the long-term mean and not the original or previous profile.

The plots in Appendix E are profile envelopes; i.e., the plots show two lines drawn through the upper and lower extremes of the surveyed sand elevations on each of the profile lines. The envelope of extremes contains points from many different surveys, rather than tracing a particular eroded or accreted profile found during one survey.

b. Empirical Eigenfunction Analysis.

The temporal and spatial variability of each beach profile was also examined using empirical eigenfunction analysis. The results of this analysis are presented in Appendix F. Although widely used in other scientific disciplines (Lorenz, 1959), this analysis has only recently been applied to separating sources of variability in coastal processes.

When applied to analysis of profile lines resurveyed over a period of time, the method quantifies the topographic variability in both the onshore-offshore and longshore directions through time. The technique has been applied to studies on beaches, islands, and other coastal features on both the Atlantic and Pacific coasts (Winant, Inman, and Nordstrom, 1975; Vincent, et al., 1976; Resio, et al., 1977; Aubrey, 1979; Miller, Aubrey, and Karpen, 1980; Miller, 1982). This technique provides a useful supplement to the "traditional" analytical procedures described above.

Eigenfunctions of the beach profiles were calculated in two ways. The first set (the *mean* eigenfunctions) was calculated on the entire profile, before removing the mean shape of the beach. The second approach was to subtract the arithmetic mean profile before calculating eigenfunctions (the *de-meaned* eigenfunctions). The two sets of eigenfunctions have

---

* Appendices B-G are on file at the US Army Engineer Waterways Experiment Station and are available for loan.

NO. OF SURVEYED PROFILE LINES
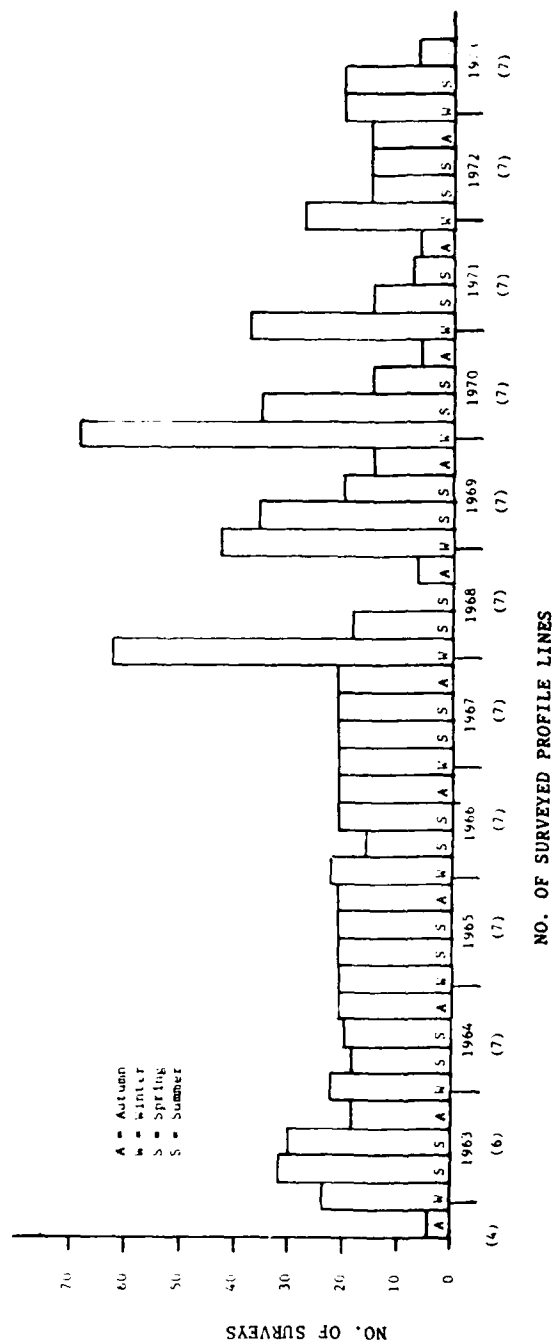
Figure 6. Frequency distribution of profile line
surveys by season and year

18

No. of Surveys

160 140 120 100 80 60 40 20

D   J   F   M   A   M   J   J   A   S   O   N

WINTER   SPRING   SUMMER   AUTUMN
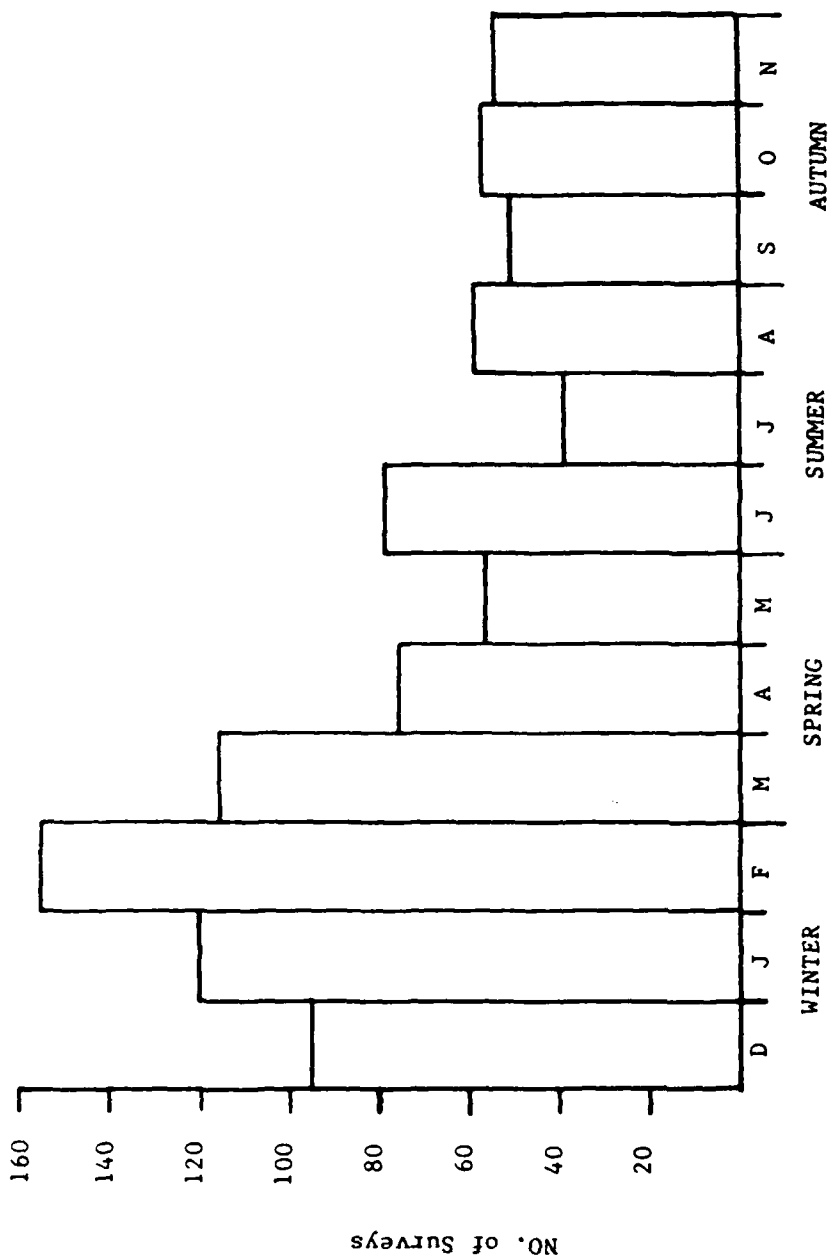
Figure 7. Frequency distribution of profile line surveys by month and season

19
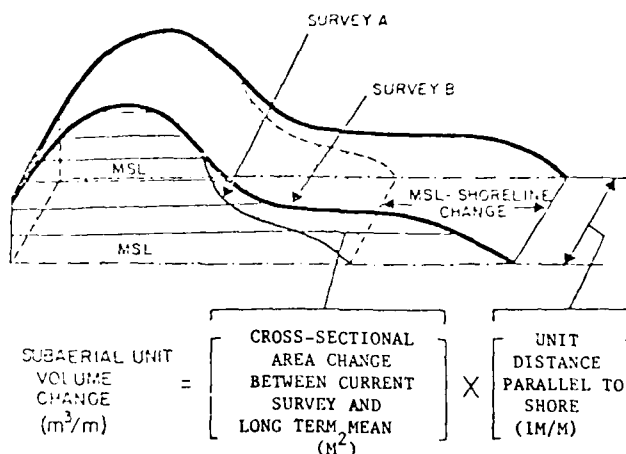
Figure 8. Definitions of MSL shoreline
change and above MSL unit volume change
(after DeWall, 1979)

different properties; but, in general, the nth *de-meaned* eigenfunction is analogous to the (n+1) *mean* eigenfunction. Both calculations are useful for describing changes in beach configuration.

IV. RESULTS

1. **Wave Data.**

Sediment accretion and erosion on Misquamicut Beach are controlled primarily through interaction between the beach and the surface wave field. The routes and rates of sediment transport can best be predicted through direct local observations of the varying wave field. The alternative to direct local wave observations is to propagate waves of specified height and period from a distant offshore site shoreward toward the study area using linear refraction techniques.

a. **Direct Local Observation.** The only two sets of direct wave observations available for this region are visual observations obtained as part of this study and gage measurements near the Charlestown Inlet (Fig. 1) (Raytheon Corporation, 1975). The accuracy of visual observations is limited and the utility of the gage measurements is restricted by insufficient statistical information. Furthermore, the directional resolution provided by the visual observations is insufficient to permit accurate sediment transport calculations and the wave gage data provide no directional information at all.

Additional wave data were collected by CERC (Thompson, 1977) from 23 January 1964 to 18 April 1965 using a pressure gage maintained at the Buzzards Bay Tower. The gage was located in 19.2-meter water depth and positioned 2 meters below the water surface. Pen-and-ink records were analyzed and the results compiled. No directional information was collected. Monthly mean significant wave heights and periods show that September is the most energetic month with the longest period waves (Fig. 9). Except for September (with a mean period of about 9 seconds), the mean period is close to 7 seconds. Mean annual significant wave height is 0.75 meter.

Figure 9. Summary of monthly mean significant wave heights and periods at Buzzards Bay Light Tower, January 1964–April 1965 (Thompson, 1977)

21

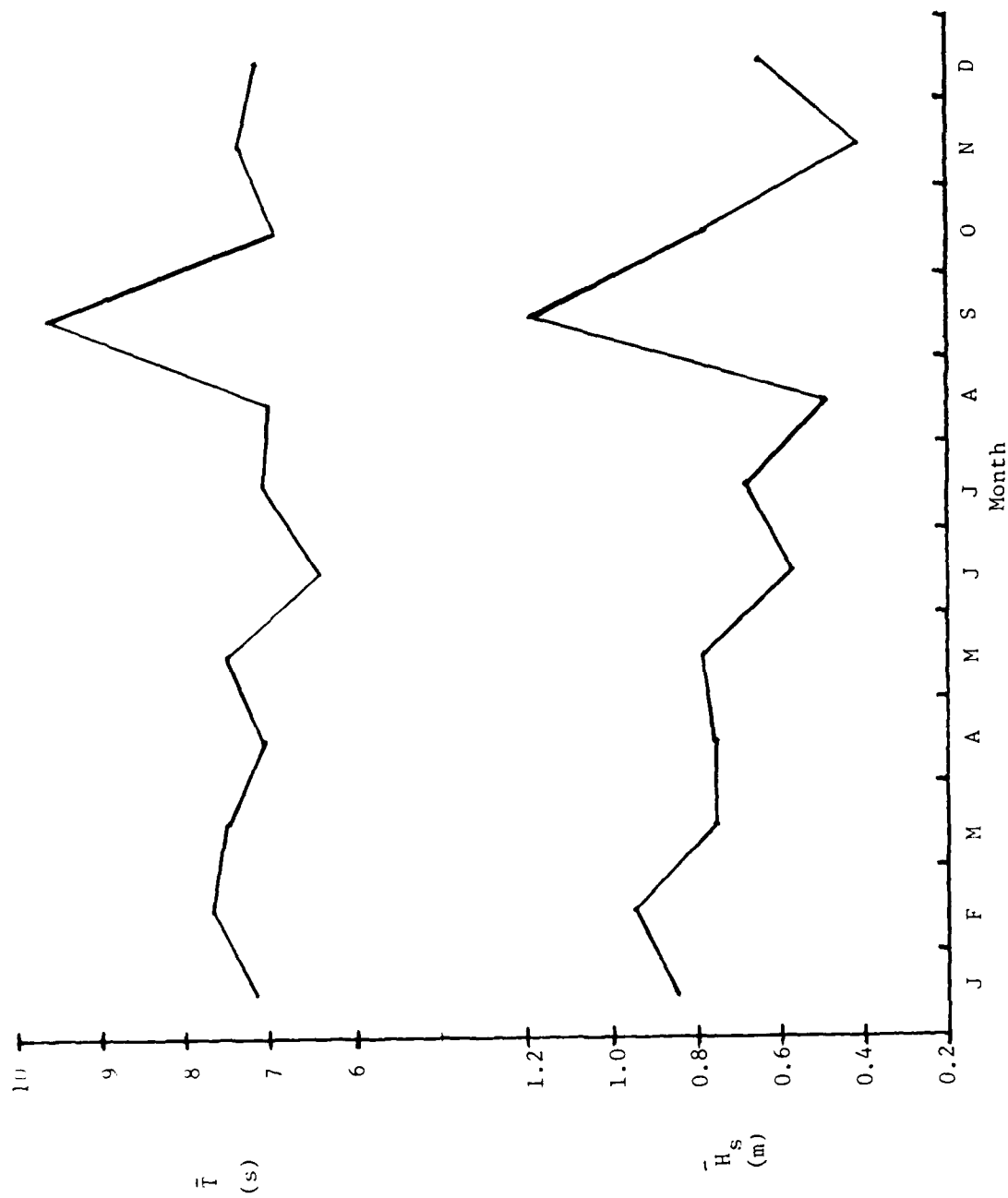For comparison, tabulation of wave observations at Watch Hill Point for the period of January 1968 through December 1975 provides a view of seasonality of wave conditions (Fig. 10). Over this period of time, there were approximately 22 visual observations per month. Yearly mean breaker height was approximately 0.5 meter, with a mean yearly period of 8.6 seconds. Mean wave direction is from just east of south.

A plot of the percent exceedance of given wave heights for the Buzzards Bay data (Fig. 11) shows that for 10 percent of the time significant wave heights exceed 1.7 meters and 1 percent of the time significant wave heights exceed 2.9 meters. The significant wave height, H_s, can be related to the root-mean-square wave height, H_{rms}, by

$$H_s = \sqrt{2}\, H_{rms}.$$

For nearshore wave conditions, H_{rms}, is a better quantity for intercomparing wave activity. At the Buzzards Bay Tower, the mean annual value of H_{rms} is 0.5 meter.

b. <u>Linear Wave Refraction</u>. A wave propagation refraction modeling technique (Dobson, 1967) was used to develop a qualitative analysis of the surface wave field off Misquamicut Beach. This method employs the wave height and period statistics collected by direct observation, and assumes a uniform offshore directional distribution of the field. Based on the results of the Buzzards Bay study, linear refraction was calculated for waves with periods of 4, 7, and 10 seconds propagating in $15°$ directional segments covering the $180°$ offshore sector for Misquamicut Beach. The results of these calculations are presented as ray plots in Appendix G.

The applicability of the Buzzards Bay wave data to Misquamicut Beach must be qualified for two reasons. During the monitoring period at Buzzards Bay, two storms with 20-year recurrence intervals occurred (September 1964), resulting in higher than average mean significant wave heights for that month (from David G. Aubrey's unpublished storm compilation). In addition, there was a higher incidence of high intensity storm events in 1964 than the average for the surrounding 10 years. Therefore, the Buzzards Bay data may not be representative of the long-term average.

Furthermore, Misquamicut Beach is located about 55 kilometers from the Buzzards Bay site, so differences between wave climates at the two sites are inevitable. One specific difference in wave climate is the shadowing of the Misquamicut site by Block Island. Conversely, the Buzzards Bay site is more neavily shadowed than Misquamicut by the Elizabeth Islands and Cape Cod for some wave directions. These differences in wave climate must be recognized when employing wave data from one location at another site.

The wave refraction plots (App. G) indicate that there is significant longshore variability in the wave energy incident on Misquamicut Beach. Zones of divergence and convergence of wave energy vary as a function of offshore wave direction. This sensitivity to offshore wave direction appears to result from refraction caused by the submerged valley extending through Block Island Sound toward the Block Channel.

2. <u>Beach Profile Changes</u>.
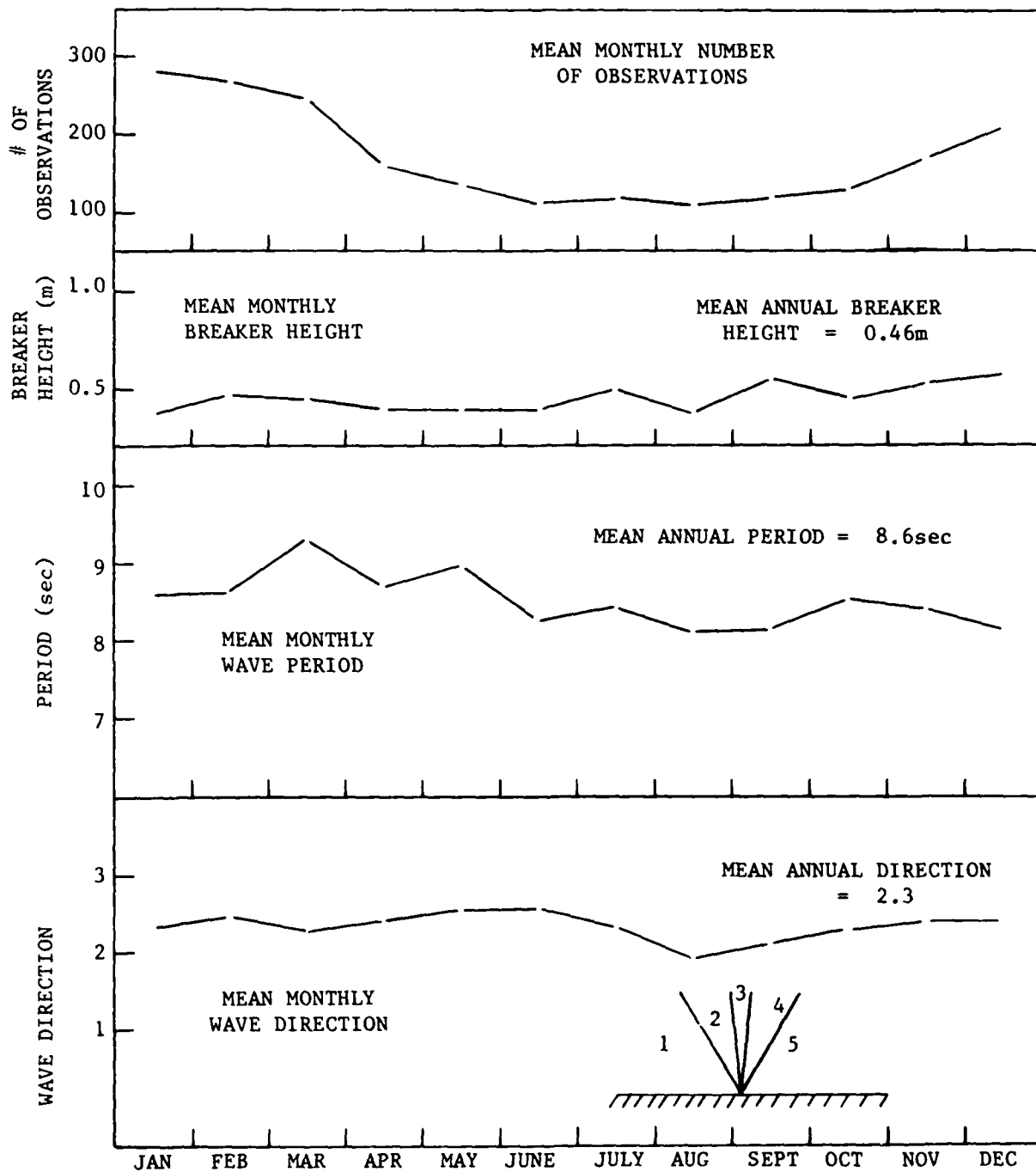
Figure 10. Wave observations, Watch Hill Light Station,
January 1968-December 1975
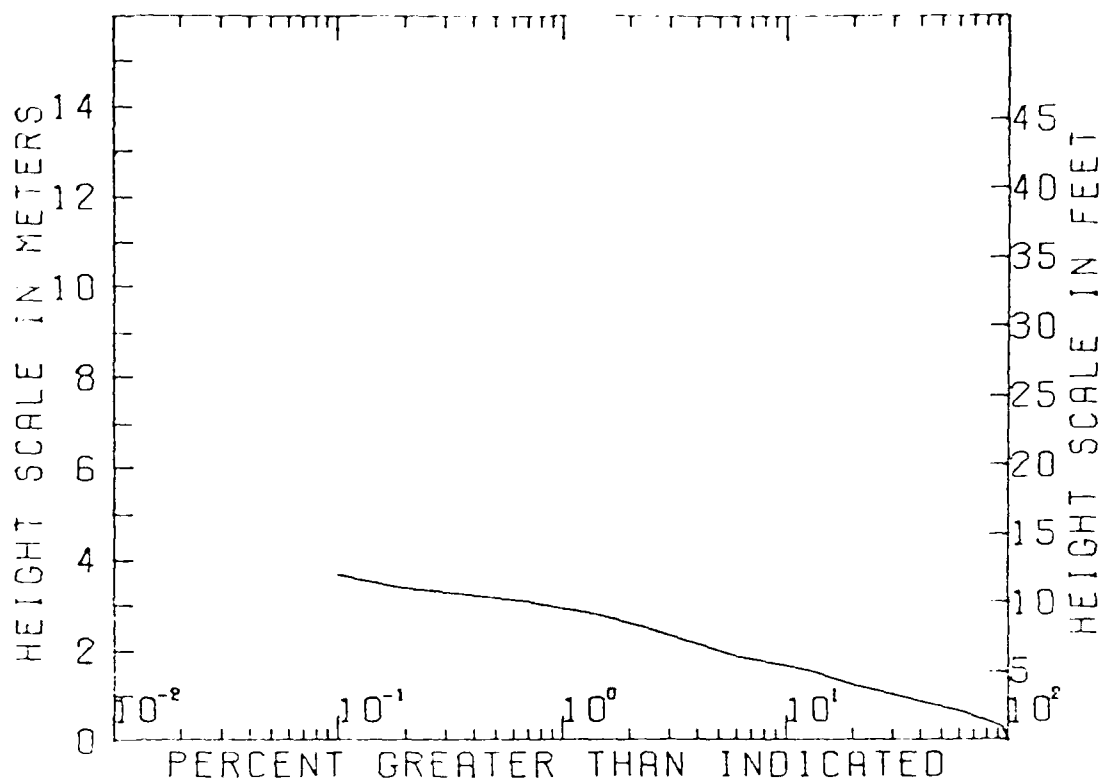
Figure 11. Mean annual cumulative wave height distribution at
Buzzards Bay, 1964-1966 (Thompson, 1977)

a.   Long-Term Beach Changes. Long-term trends in above MSL volumes and intercepts were combined with results from eigenfunction analysis to quantify trends in beach evolution along Misquamicut Beach. Detailed plots for volume and mean sea level intercept for each profile line are presented in Appendixes C and D. Plots of eigenfunction analysis are presented in Appendix E.

Linear regression analyses were run for each profile line to determine trends in MSL volume and intercept (Table 2).

Table 2

Slope of Linear Regression Line and Coefficient of Determination

for Changes in Above MSL Volume and MSL Intercept with Time

Profile Line	Above MSL Volume (m^3/m/yr)		MSL Intercept (m/yr)	
	Slope	r^2	Slope	r^2
1	+82.10	0.9419	-0.46	0.0689
2	+12.53	0.5004	-0.18	0.0087
3	+ 4.59	0.7354	+0.12	0.0027
8*	+ 3.01	0.4389	-0.84	0.1104
5	+ 0.59	0.0485	+0.32	0.0765
6	+ 0.65	0.0831	+0.15	0.0307
7	+ 1.55	0.6299	-0.0024	0.0000
4**	+ 2.52	0.1217	+0.20	0.0030

 * Line 8:   1967-1973.
** Line 4:   1964-1967.

There are no significant trends in MSL intercept; however, there are significant trends in the volume above MSL. Profile line 1 shows a definite increase in volume over the period of study, with an average accretion rate of 82 cubic meters per meter per year. Profile lines 4, 5, and 6 show no significant trends, and all others are accreting at low rates.

Long-term trends can be determined from regression analysis of the temporal dependence of the first mean eigenfunction. The first eigenfunction, called the mean beach function, has proven useful in determining trends in beach evolution through time. Analyses of the eigenfunctions confirm the net accretional trend for profile lines 1, 2, 3, 7, and 8 and show no net trend for lines 4, 5, 6, and 7 (Table 3).

Table 3

Percent Annual Change in Volume Along Profile Lines
with Coefficients of Determination (r^2)

Profile Line	Percent Yearly Change in Volume*	r^2
1	+4.5	0.66
2	+1.1	0.67
3	+1.5	0.60
4**	+0.31	0.37
8†	+1.5	0.66
5	+2.0	0.003
6	+0.3	0.075
7	+2.1	0.224

* Determined from regression slope for first mean temporal eigenfunction.
** Line 4: 1964-1967.
† Line 8: 1967-1973.

The greatest percent accretion occurs along profile line 1, against the west jetty at Weekapaug Inlet (Figs. 12 and 13).

b. Seasonal Beach Changes. Seasonal beach change patterns are often obscured by high intensity, evenly distributed storm events. In spite of this, variations in MSL intercept, above MSL sand volume, and eigenfunctions (particularly for years 1970-73) indicate a consistent seasonal fluctuation at Misquamicut Beach. Seasonality in beach response is apparent in both MSL volume and intercept plots along profile line 1, for example (Figs. 14 and 15).

The MSL volume change plots show a consistent tendency for erosional events to occur during the winter months; however, erosional events can occur during any season, in response to the incidence of storm events throughout the year. Along profile lines 1,2,3, and 5, there is a distinct seasonal cycle in erosion-accretion in 1963-1967 and 1970-1973 (Appendix C). Lack of seasonality in 1968-69 may be due to the unevenly distributed sampling in those years (Fig. 6); however, the most distinct seasonal response is from 1970-1973, a period when sampling was not as uniform as from 1963-1967. Seasonal changes are not as evident in the MSL-shoreline position plots (Fig. 15), supporting the observation that MSL-volume and MSL-intercept plots are not always correlative. Some tendency for smaller winter MSL-intercept values can be seen at lines 1,2,3, and 5 (App. D).

The seasonal tendency for beach change can be better illustrated by a plot of MSL-volume averaged by month over the 11 survey years and all profile lines (Fig. 16). The figure illustrates an average building-up (accretion or positive change) of the beach in the months from March through September, with erosion (negative values) the rest of the year. Although this averaging

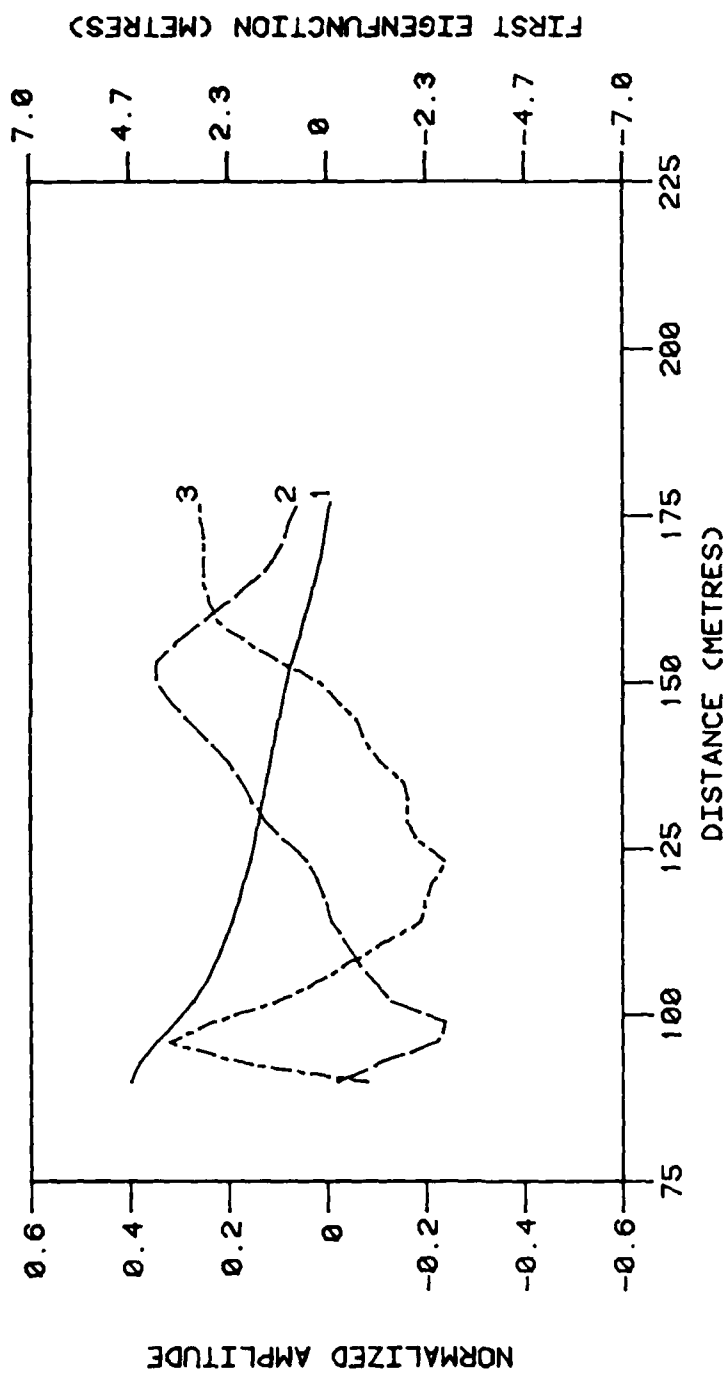Figure 12. Spatial eigenfunctions for profile line 1 (data not de-meaned)
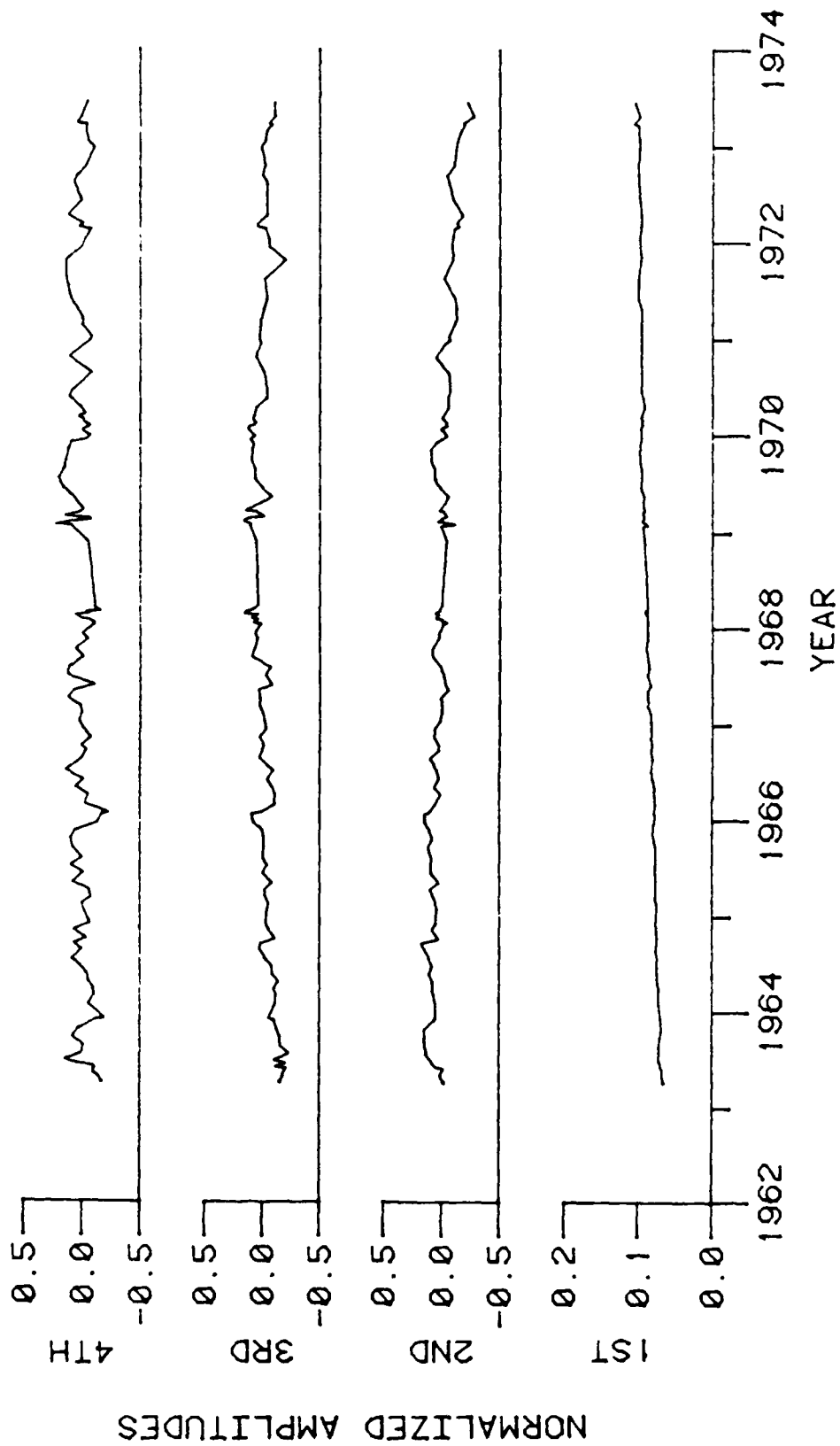
27

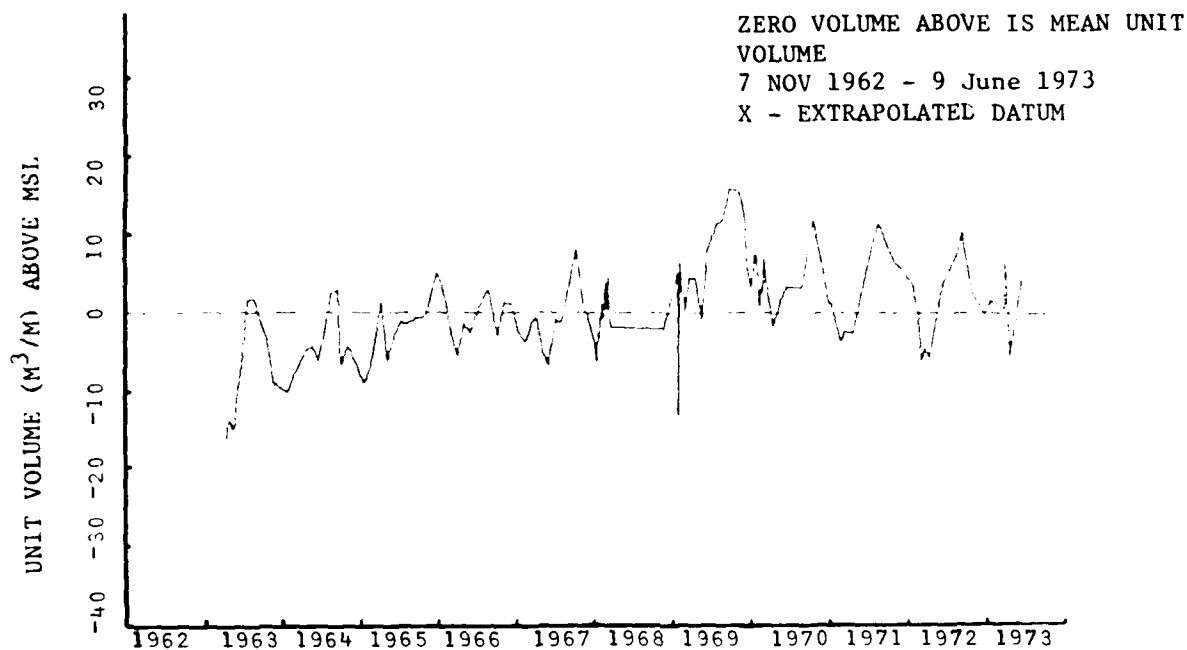Figure 13. Temporal eigenfunctions for profile 1 (data not de-meaned)

28

Figure 14.   Unit volume changes for profile line 1,
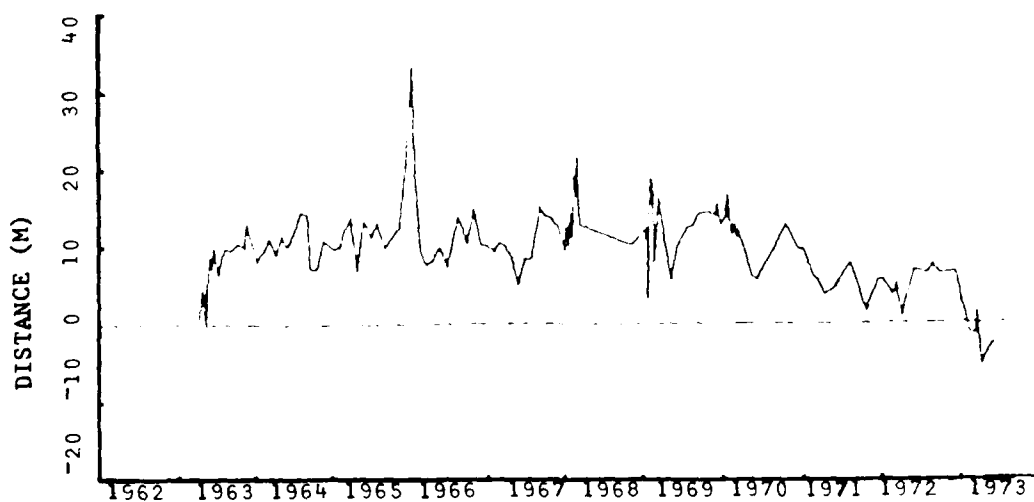Misquamicut Beach

Figure 15.   Change in distance to shoreline at profile line 1,
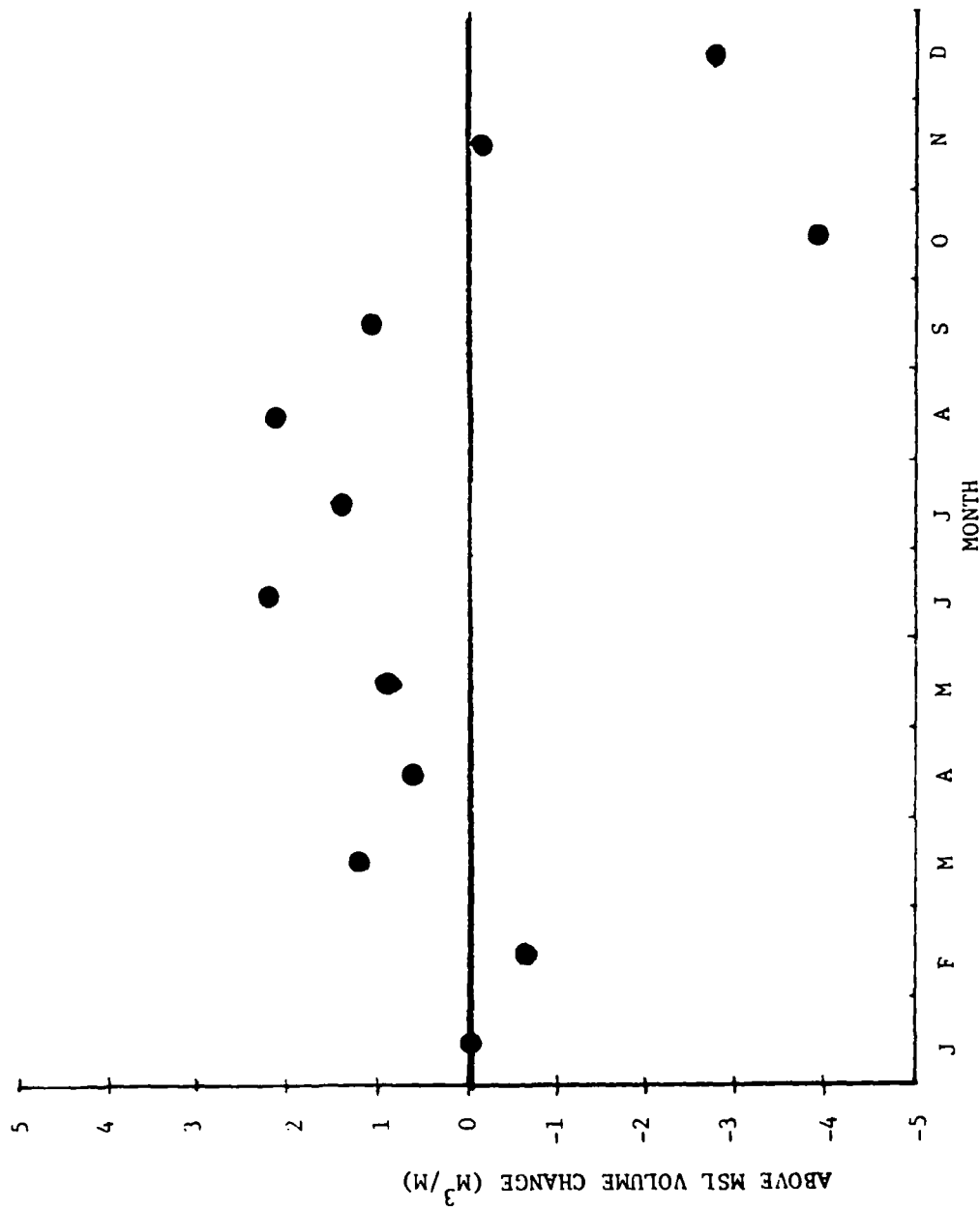Misquamicut Beach

29

Figure 16. Net monthly volume changes averaged over all profile lines throughout the survey period

obscures finer details of beach behavior, it does show a distinct seasonal pattern to beach changes.

Beach eigenfunctions (specifically the second mean eigenfunction and first de-meaned eigenfunction) also indicate seasonality for profile lines 1,2,3, and 5 for the period 1970-73 (App. F). Quantification of this seasonal variability is provided by the eigenvalue of these eigenfunctions. A comparison of the values for different lines can indicate longshore variability in beach response, as well as provide a comparison for other beaches with different wave exposure. Table 4 illustrates the trend in longshore seasonal variability at Misquamicut Beach. Beach variability (shown by the total mean square variance, MSV, for the beach face profiles with means removed) is greatest at profile lines 1 and 2 which are nearest the jetties off Weekapaug Inlet. These beach variability values are about 10% of the values of outer Cape Cod beaches (Miller and Aubrey, in preparation, 1982), illustrating the difference in beach response between open ocean beaches (mean significant wave height of about 1.0 meter) and relatively sheltered beaches wth limited fetches (mean significant wave height of about 0.5 meter).

c. <u>Short-Term Beach Changes</u>. Profile data for the period April 1963 to June 1973 indicate that the shoreline along Misquamicut can display significant short-term variability. The majority of these variations appear to be the result of naturally occurring erosion-accretion cycles induced by the passage of high energy storm events. Two primary storm types affect the Misquamicut area: the tropical storm, generally an intense low pressure system formed over the southern north Atlantic and propagating to the north and east along the east coast of the United States, and the more common coastal storm produced by the passage of a low pressure system initially formed either inland (in the midwest or central Canada) or along the east coast (typically in the vicinity of Cape Hatteras). The impact of these events on the beach depends primarily on the intensity of the individual storm and its trajectory or track line and the antecedent beach configuration. For storms of equal intensity, maximum energy conditions along the beach result from storms tracking to the east of the site due to the orientation of Misquamicut Beach and the sheltering provided by Long Island and Block Island. A number of significant storm events occurred during the BEP survey period and the profile data provide some insight concerning the character of the associated beach response.

(1) <u>Storm of 29-30 November 1963</u>. This intense coastal storm was produced by the passage of a low pressure system which formed initially along a gulf coast front, moved inland over the State of Louisiana and continued along a northeast trending track over Chesapeake Bay. Weather maps for the period indicate that by 29 November the low had moved into New Jersey and central pressures averaged 972 millibars. Continuing northward, the low merged with a second system initially formed over the Great Lakes and the combined depression moved northeastward into Canada. The track of this system caused the center of the low to pass close by the Misquamicut area the night of 29-30 November. By 2 December the storm was well to the north and its influence on local weather became negligible.

Winds in the Misquamicut area for the period 27 November through 1 December began as light to moderate southwesterlies shifting to the northeast and intensifving on 29 Nov mber (Fi .) s e rm cent

3

Table 4

Eigenfunction Analysis Statistics for the Beach Face Profiles

		Beach Profiles Mean Included			De-Meaned	
Profile Line	Eigen-function No.	MSV (m^2)	PCT Total MSV	PCT Residual	MSV (m^2)	PCT Total MSV
	Total	4.63			0.100	
1	1	4.59	99.19		0.077	76.9
	2	0.023	.49	59.9	0.013	12.9
	3	0.007	.15	19.0	0.004	3.6
	4	0.003	.05	6.8	0.002	2.0
	Total	15.38			0.116	
2	1	15.3	99.45		0.063	54.3
	2	0.035	0.22	40.8	0.026	22.6
	3	0.025	0.16	29.5	0.010	8.9
	4	0.010	0.06	11.6	0.004	3.4
	Total	5.62			0.054	
3	1	5.58	99.34		0.026	47.6
	2	0.024	0.42	64.0	0.005	32.2
	3	0.005	0.09	13.1	0.002	9.0
	4	0.004	0.07	10.3	0.002	4.0
	Total	3.36			0.054	
4	1	3.31	98.55		0.026	47.6
	2	0.022	0.66	45.6	0.013	23.6
	3	0.012	0.36	25.0	0.006	11.3
	4	0.006	0.17	11.7	0.003	6.1
	Total	7.16			0.060	
5	1	7.11	99.31		0.037	60.8
	2	0.029	0.41	59.7	0.011	18.3
	3	0.008	0.11	16.5	0.006	9.4
	4	0.006	0.08	11.2	0.002	3.5
	Total	7.72			0.040	
6	1	7.68	99.6		0.024	58.2
	2	0.015	0.19	48.0	0.008	21.0
	3	0.008	0.11	26.7	0.003	8.5
	4	0.003	0.04	11.0	0.001	3.7
	Total	4.08			0.088	
7	1	4.02	98.6		0.059	67.0
	2	0.032	0.79	56.7	0.013	14.5
	3	0.010	0.25	17.9	0.005	6.1
	4	0.005	0.12	8.6	0.004	4.0
	Total	3.26			0.039	
8	1	3.23	98.89		0.015	37.1
	2	0.014	0.43	39.2	0.012	30.4
	3	0.011	0.34	31.2	0.006	14.6
	4	0.004	0.12	11.2	0.002	4.3

NOTE: Wind vectors point in the direction <u>toward</u> which the wind is blowing.
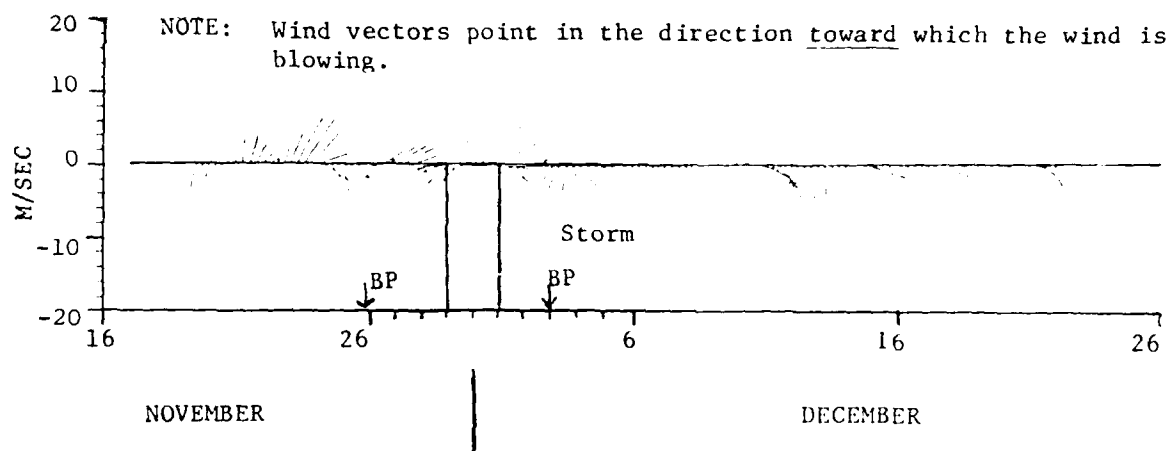
BP - beach profile survey dates

Figure 17. Wind information recorded in the Misquamicut
area, November-December 1963; Northeast storm occurred
29-30 November 1963

33

passed, wind direction shifted progressively to the southeast, south, and finally southwest. The southwesterlies displayed the maximum sustained speeds for the period.

An analysis of the beachfront profiles indicates that the storm caused significant erosion along most of the study area. A maximum sediment loss of 15 cubic meters per meter occurred in the vicinity of profile line 3 (Fig. 18). Losses decreased progressively with distance east and west of this section. Approximately 2 cubic meters per meter of sediment was lost in the vicinity of line 7 while line 1 gained 1.5 cubic meters per meter. The cause of this significant spatial variability cannot be simply established. Overall the beach front lost about 9 cubic meters per meter of sediment above MSL during the three-day storm event. Poststorm surveys indicate that this volume of sediment was returned to the beach front by April 1964 either through natural accretion or artificial fill.

(2) <u>Storms of 21 January - 1 February 1966</u>. The Misquamicut area was affected by the passage of three relatively intense low pressure systems during this period. The first formed over the mid-Atlantic states on 22 January and passed east of Rhode Island on the next day, proceeding on a northeasterly track toward the Canadian Maritimes. The average central pressure was about 992 millibars. This storm cleared the area by 25 January, to be followed by a second, more intense, low initially formed off the coast of Florida tracking northeast off the eastern seaboard. This system passed south and east of the study area on the 27th and subsequently merged with a low proceeding southeastward from Canada. The combined system moved slowly to the northeast and dominated New England weather until the 29th. The third low moved over the study area on the 30th. Initially formed along the northeastern Gulf of Mexico over the Florida panhandle, this system was similar in character to the first low although slightly more intense with an average central pressure of 970 millibars. Its track passed directly over the study area on the 30th and subsequently headed northeast toward Nova Scotia. This storm was essentially clear of the study area by 2 February.

The wind patterns produced by the passage of the first two storm systems were similar in character. In each case, the storm approach favored the generation of northeasterly winds that progressively intensified and finally shifted to the northwest as the low center passed (Fig. 19). Despite higher central pressures, the proximity of the first low to the study area resulted in higher sustained windspeeds than observed during the passage of the second low. Passage of the third low generated northeasterly winds that quickly shifted tow rd the southeast and finally settled into the southwest after the center mov. . north of the study area. These southwesterly winds displayed the highest sustained windspeeds produced by the event.

These low pressure systems exposed Misquamicut Beach to an extended period of essentially continuous high energy conditions which were sufficient to induce extensive shore front erosion along most of the study area. Profile data indicate that maximum erosion occurred in the vicinity of profile line 5 where 32 cubic meters per meter was displaced. The volume of erosion decreased to the east and west of this section with profile line 1 losing about 1 cubic meter per meter while line 7 gained 2 cubic meters per meter. Overall, the beach front lost a total of approximately 11 cubic meters per meter (Fig. 20). Poststorm surveys indicate that about 15 months

34
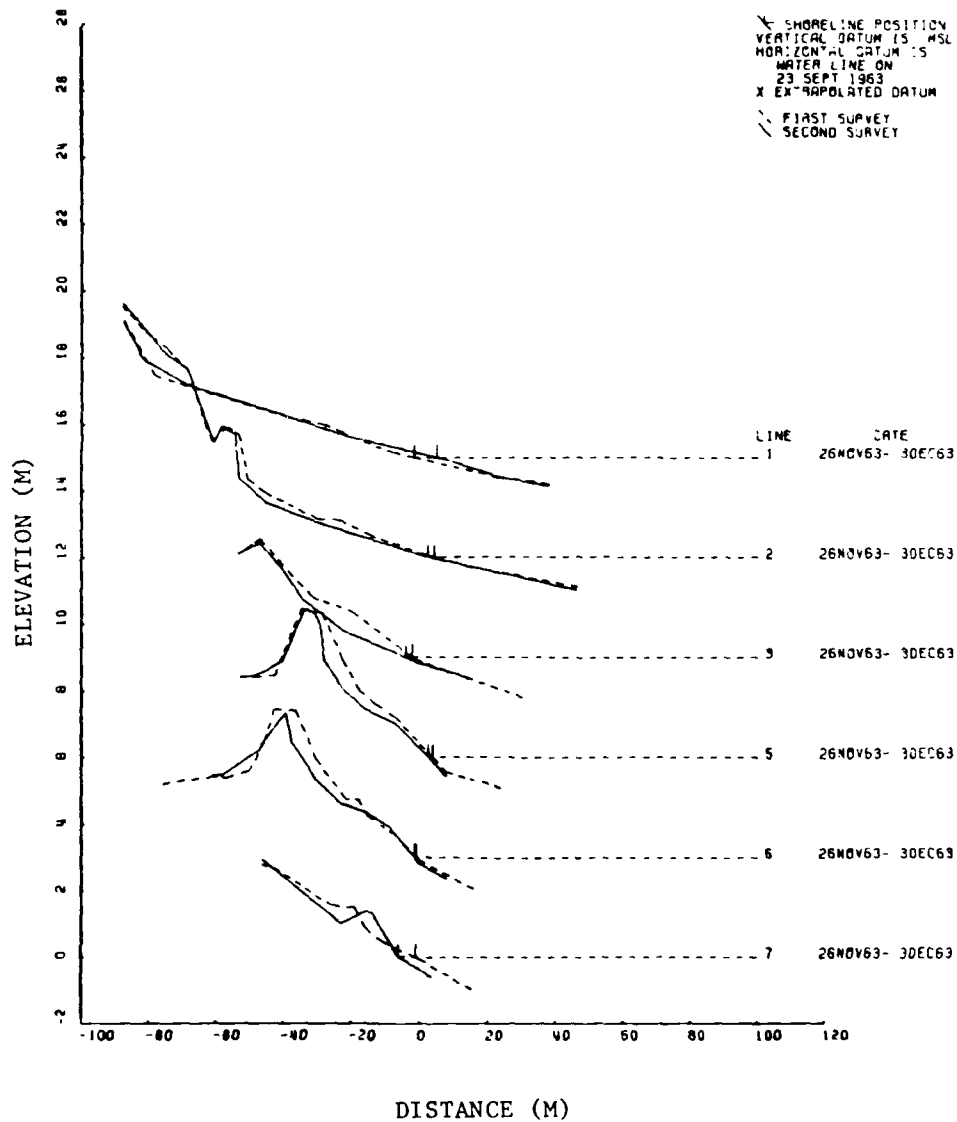
Figure 18.   Comparison of beach profiles measured at Misquamicut
Beach 26 November and 3 December 1963

35

NOTE: Wind vectors point in the direction <u>toward</u> which the wind is blowing.
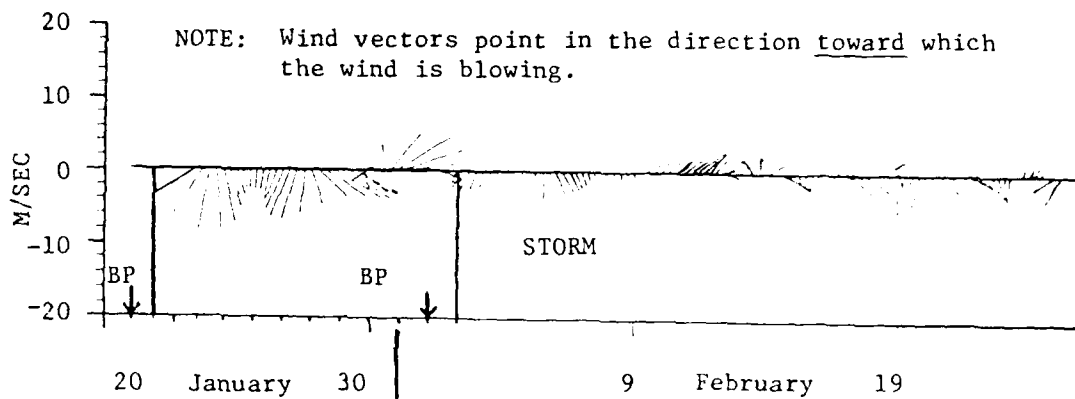
BP - Beach profile survey date

Figure 19. Wind information recorded in the Misquamicut area January–February 1966. Storms occurred 22 January–2 February, 1966

ELEVATION (M)

SHORELINE POSITION
VERTICAL DATUM IS MSL
HORIZONTAL DATUM IS
WATER LINE ON
23 SEPT 1963
X EXTRAPOLATED DATUM

FIRST SURVEY
SECOND SURVEY

LINE	DATE
1	21DEC65-21JAN66
2	21DEC65-21JAN66
3	21DEC65-21JAN66
4	21DEC65-21JAN66
5	21DEC65-21JAN66 X
6	21DEC65-21JAN66
7	21DEC65-21JAN66

DISTANCE (M)

Figure 20.   Comparison profiles measured at Misquamicut Beach
21 January and 1 February 1966

37

were required before accretion was sufficient to offset this loss of sediment. The time required for beach recovery following this storm period strongly suggests that the rapid recovery of profile line 3 following the November 1963 storm was due to artificial fill.

(3) Storm of 14 January 1968. This event was a short-lived, intense coastal storm produced by the passage of a low pressure system which formed initially over Kentucky and Tennessee and subsequently followed a northeastward route over the study area. Prior to storm passage on 14 January a large high pressure system had dominated the northeastern states' weather for more than 6 days. Profiling conducted on 10 January showed relatively little sediment movement during the preceding month. As the storm approached on the 13th, the high was displaced eastward and winds shifted from the northwest through the north to the northeast and intensified (Fig. 21). The system moved over the study area in about 24 hours, with winds shifting to the south, then southwest and finally back to the northwest as a high returned to the area on the 16th.

Visual observations indicate that this event generated a surface wave field off Misquamicut Beach with characteristic heights of 1 to 1.3 meters and periods of about 10 sec. At breaking, the direction of advance of these waves was essentially shore perpendicular. Beach profiles obtained on 15 January indicate that this wave field induced general erosion along the eastern sections of the beach. With the exception of profile line 1, where slight accretion was observed (0.34 cubic meters per meter) all lines displayed a net loss of sediment ranging from a high of 11.23 cubic meters per meter at line 2 to a low of 3.15 cubic meters per meter at line 7 (Fig. 22). Although a slight secondary maximum was observed in the vicinity of profile line 8, erosion along the midsection of the study area was essentially uniform but suggestive of a progressive decrease in erosion from east to west. Overall above MSL erosion losses during this event were about 6 cubic meters per meter. Surveys conducted during late January and February 1968 indicate that this loss was balanced by accretion along the study area in less than 1 month.

(4) Storm of 11 December 1969. This storm was produced by the passage of a low pressure system formed over northwestern Florida along the southern limit of a large cold front extending north along the entire eastern seaboard. This low which followed a northerly track, passed to the west of the study area on 11 January and proceeded into Canada. Winds for the period preceding the storm were primarily from the northwest with brief periods of east to southeasterly winds during the cold front passage (Fig. 23). As the storm approached, winds shifted clockwise from the northwest through the northeast to the southeast and then southwest. Winds from the southerly sectors displayed the maximum sustained speeds. Storm passage in coincidence with perigean high tide produced a significant tidal anomaly at Newport, Rhode Island, increasing the maximum high water levels by about 0.3 meter (Fig. 23). Visual wave observations for the storm period show wave heights of 1.3 meters and periods of 8.4 seconds with waves approaching normal to the beach.

The profile data indicate that this event produced general erosion throughout the study area. Maximum erosion occurred in the vicinity of profile lines 3 and 8 which displayed losses of 13.26 cubic meters per meter and 14.61 cubic meters per meter, respectively. Minimums were observed

38

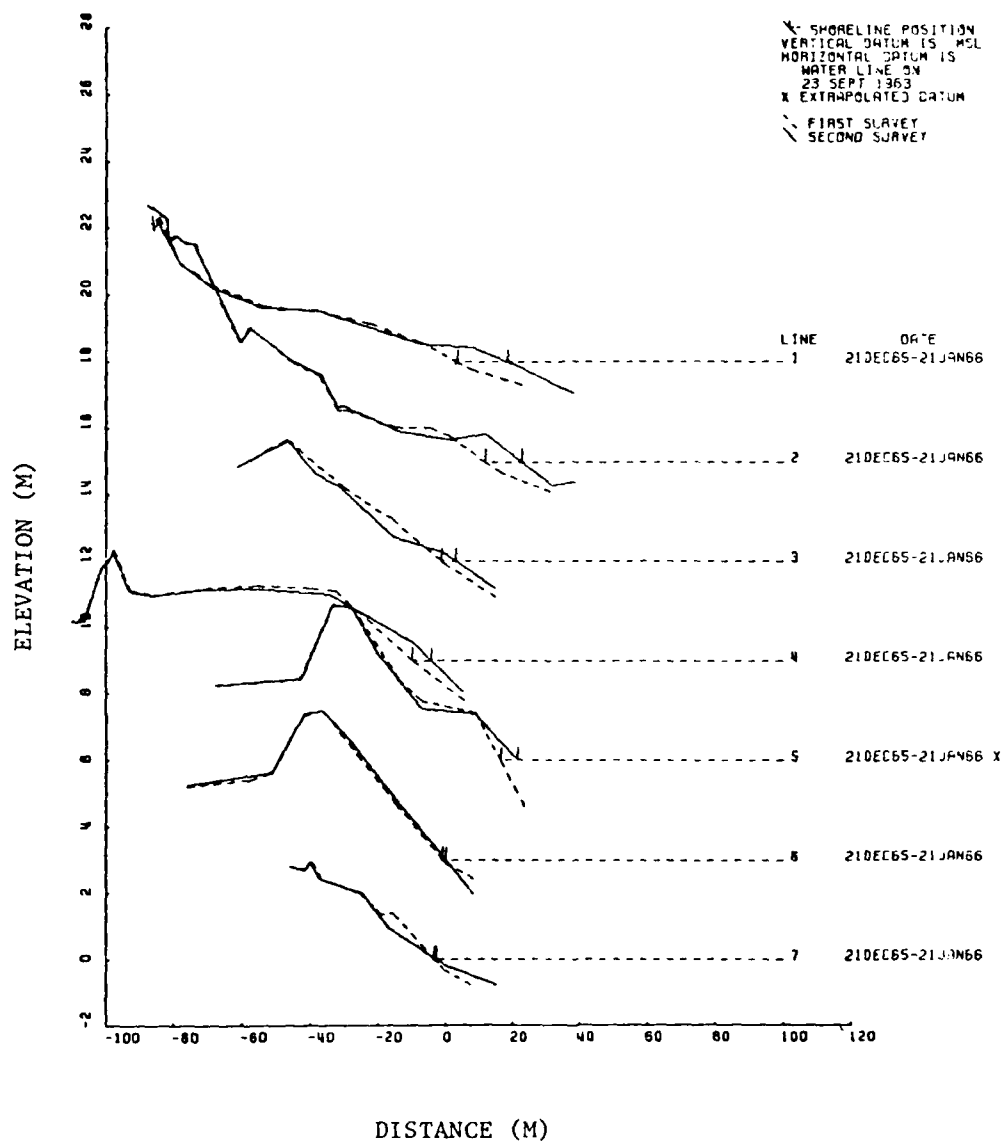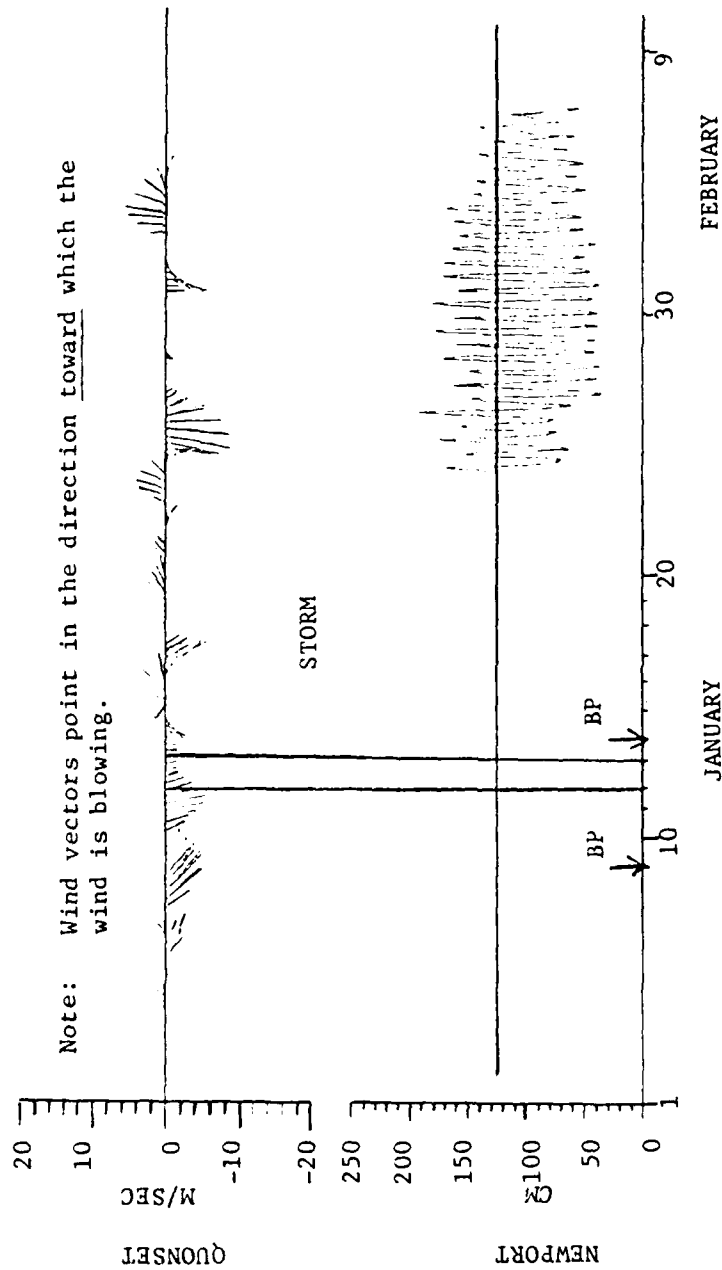Figure 21. Wind and tide information recorded in the Misquamicut area January-February 1968. Northeast storm occurred 13-14 January 1968
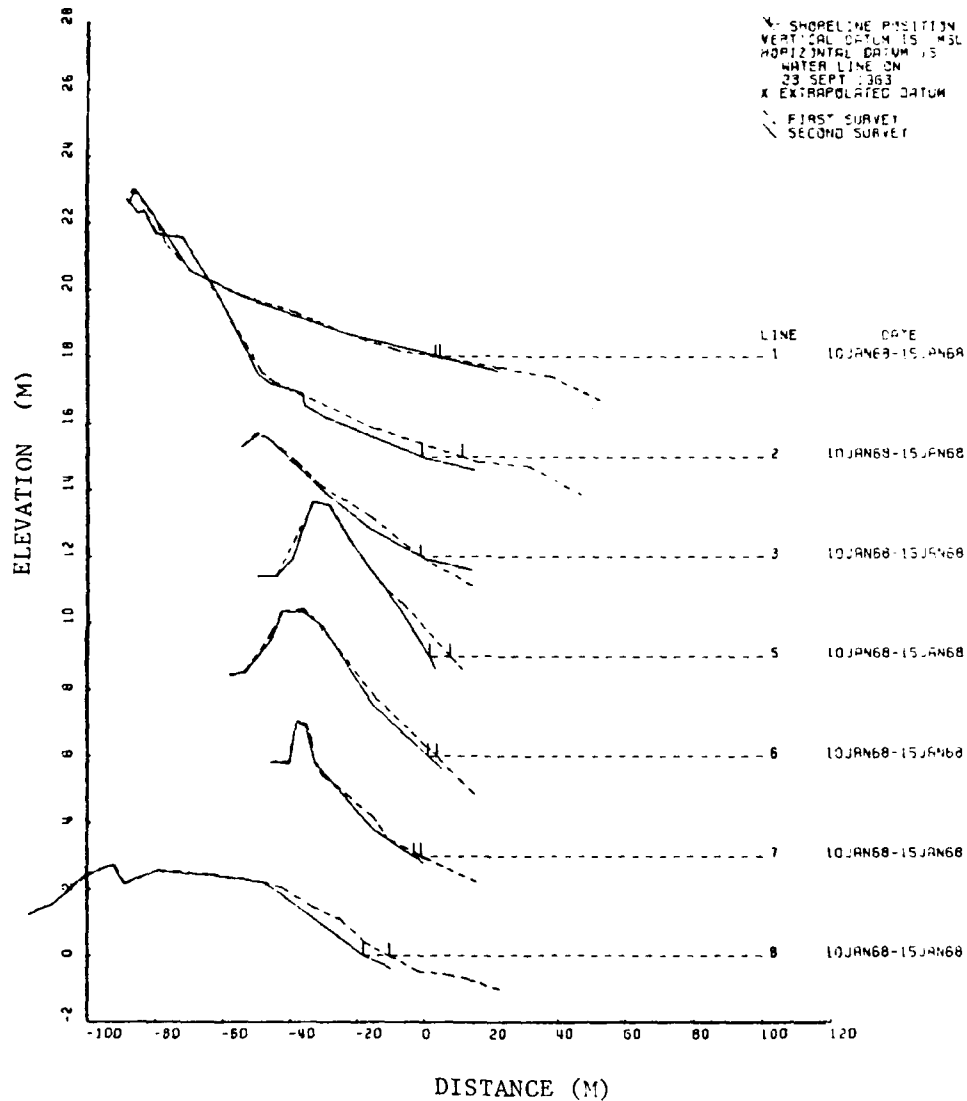
39

Figure 22. Comparison of beach profiles measured at Misquamicut
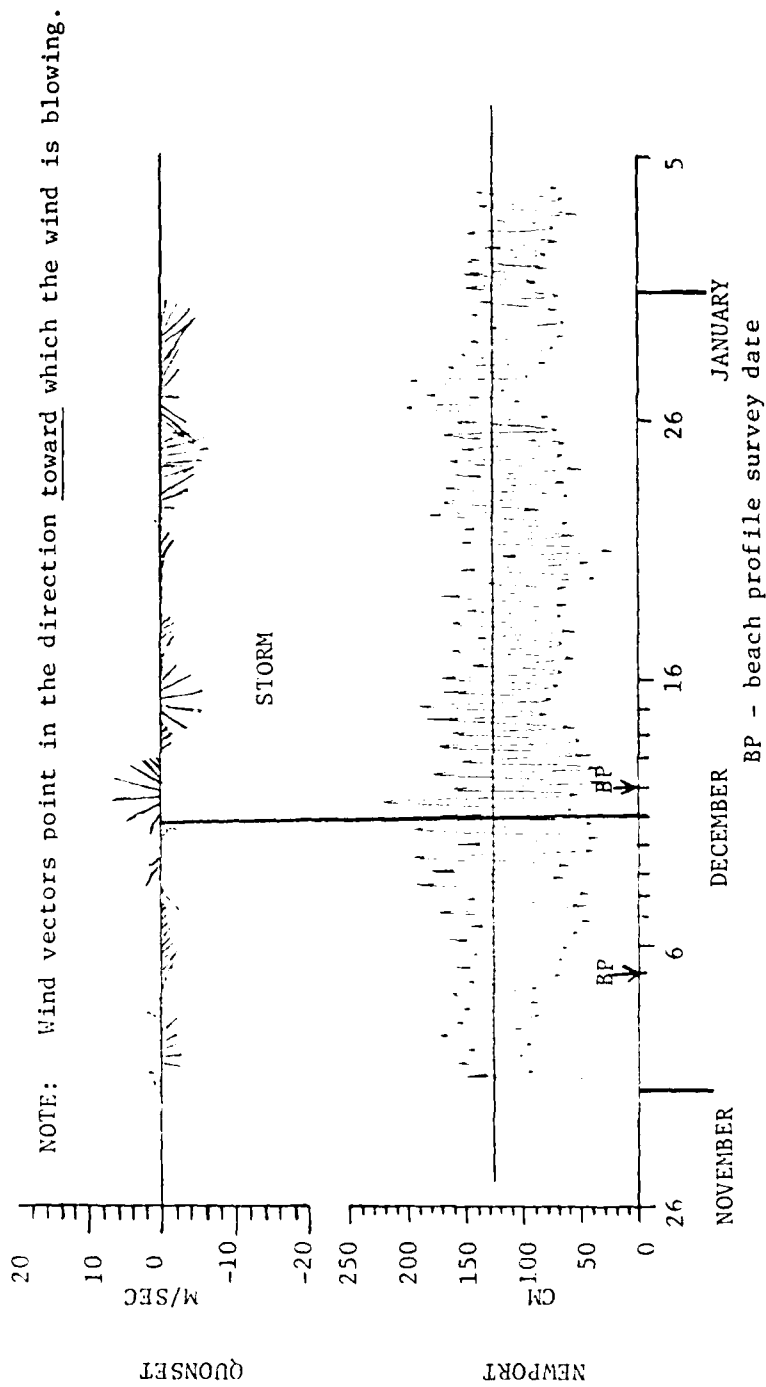area 10 January and 15 February 1968

40

Figure 23. Wind and tide information recorded in the Misquamicut area November–December 1969. Storm occurred 11 December 1969

41

in the vicinity of profile lines 1 and 2. Along the western limit of the study area the observed losses were between these two extremes, with about 10 cubic meters per meter displaced adjacent to line 7. Overall 9.8 cubic meters per meter above MSL were lost from the beachfront (Fig. 24).

(5) Storm of 2-3 February 1970. This coastal storm was the result of a low pressure system generated in the vicinity of Cape Hatteras and migrating northward along a large-scale cold front. The system formed initially on 1 and 2 February and impacted the study area on the 3rd. Winds during the peak of the event were primarily from the south-southeast (Fig. 25) and storm passage produced a surge in tidal elevation of about 0.32 meter. (Fig. 25).

Profile data show that this event induced general erosion along the study area with maximum losses occurring at profile line 8 (12.71 cubic meters per meter) and line 5 (12.45 cubic meters per meter). Minimum loss occurred at line 7 (2.69 cubic meters per meter). The remaining lines displayed essentially equal losses of about 6 cubic meters per meter (Fig. 26). The total loss along the beach front was 7 cubic meters per meter. Surveys indicate that accretion replaced 95 percent of this loss within 1 month.

The response of the study area to all these events is essentially identical. Erosion is generally widespread with maximums typically occurring in the vicinity of the central part of the beach in the vicinity of profile lines 3, 8, and 5. It is tempting to hypothesize that this is the result of wave focusing induced by offshore bathymetry. The relatively rapid recovery of the beach following erosion events suggests that sediments are either being resupplied through artificial fill or are being simply moved offshore into the bar system, stored, and returned during interstorm periods.

3. Longshore Sand Transport.

Because of the nature of the wave observations available in this area, calculations of annual longshore sand transport rates were not made. The coarseness of the directional grid as well as shoaling peculiarities at Watch Hill Point preclude a precise quantitive estimate of longshore sand transport. The wave data do support the concept of an east-to-west net longshore sand transport (Fig. 9). Yearly mean breaker directions are 2.3, indicating waves coming from east of south. At no time do monthly mean values show a higher percent of waves in sector 4 or 5 (generally much less than 10% come from these westerly sectors). Although it would be preferable to generate a joint probability distribution between wave direction and height (this was not done for this study because of the coarseness of directional bands), the directional observations give a clear picture of net transport direction.

For an upper bound on net longshore sand transport, one can assume a mean breaker height of 0.46 meter at a period of 8.6 seconds breaking at an angle of 12.5° east of the beach normal.

Then to a rough degree of approximation,
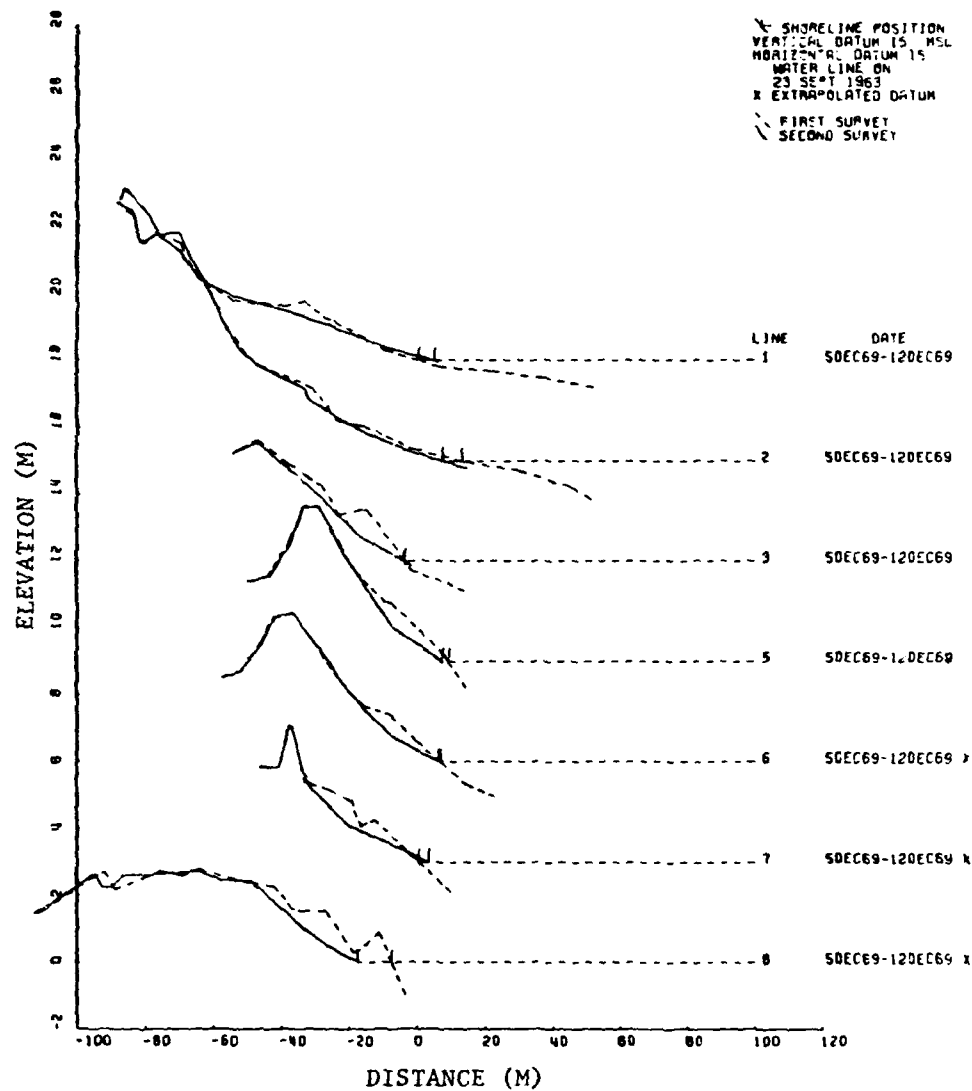
Figure 24. Comparison of beach profiles measured at
Misquamicut area, 5-12 December 1969

43

NOTE: Wind vectors point in the direction toward which the wind is blowing.
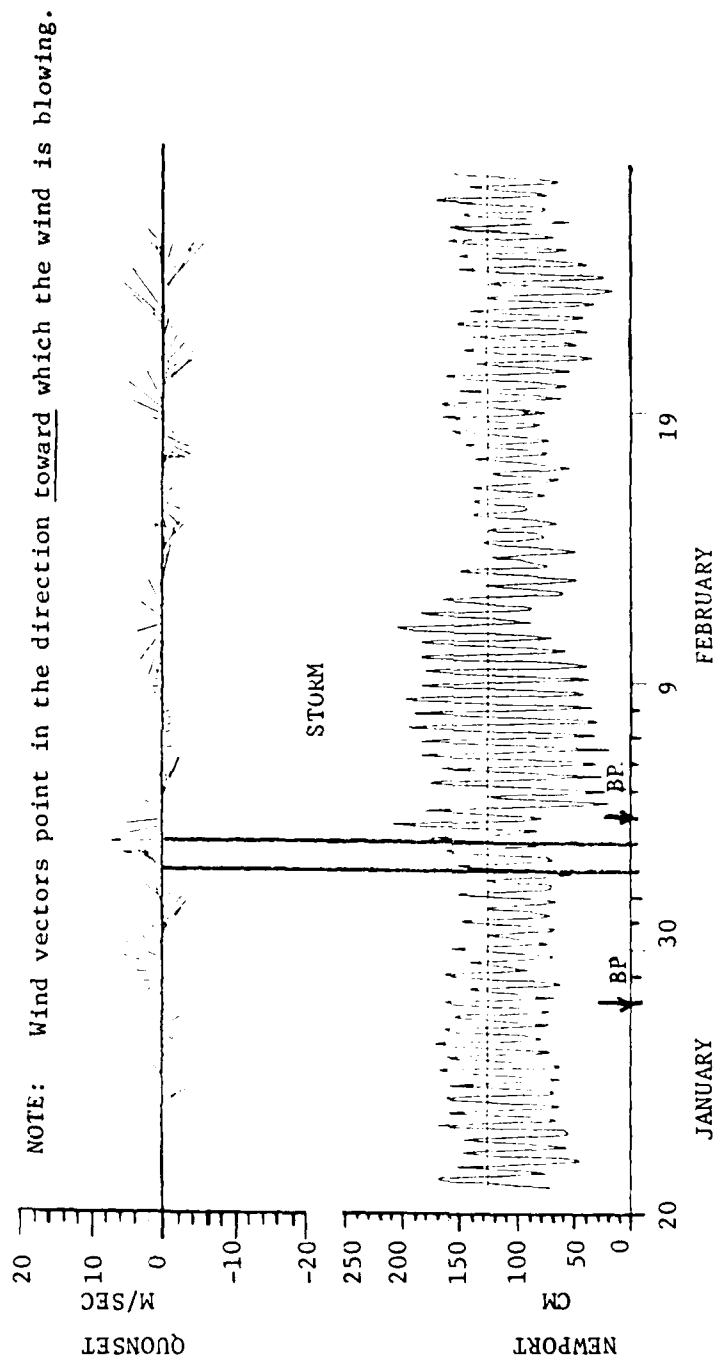
Figure 25. Wind and tide information recorded at Misquamicut area
January-February 1970. Storm occurred 2-3 February 1970

BP - beach profile survey date

44
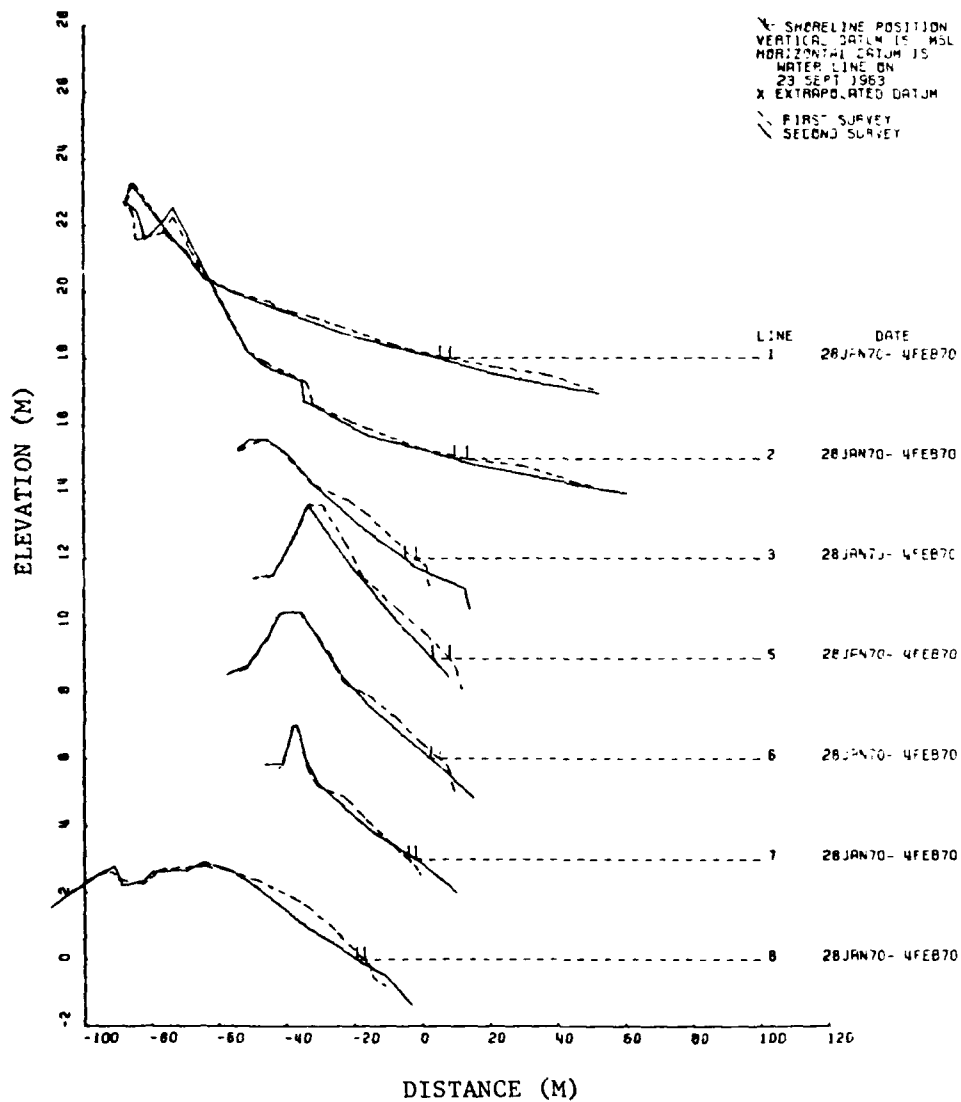
Figure 26.   Comparison of beach profiles measured at
Misquamicut Beach 28 January and 4 February 1970

$$P_{1s} = \frac{\rho g}{16} H_b^2 \, C \sin 2\alpha_b$$

$$= \frac{(1.0)(981)}{16} (46)^2 (24) \sin 25^\circ$$

$$= 1.32 \times 10^6$$

$$I_1 = (0.78)(1.32 \times 10^6) = 1 \times 10^6 \quad gm \ cm/sec^3$$

$$= \text{Immersed weight longshore transport rate}$$

$$S_1 = \frac{I_1}{(\rho_s - \rho)gN_o} = \frac{1 \times 10^6}{(1.67)(981)(0.6)} = 1 \times 10^3 \ cm^3/sec$$

$$= 30{,}000 \ m^3/yr$$

$$= \text{Volume Transport Rate}$$

Although this estimate of net longshore transport rate is very rough (due to averaging techniques), it is probably a reasonable order of magnitude estimate.

V. SUMMARY

The barrier beaches along Misquamicut, Rhode Island, are nearly linear, interrupted by slight longshore irregularities, and are composed of medium sand. They are subjected to a mean tidal range of 0.8 meter, and a low to moderate energy wave climate. The wave climate is significantly modified by sheltering, primarily by Long Island, Fisher's Island, and Block Island.

The direction of greatest fetch is to the south, between the islands. Minimum fetch from offshore directions is from the east (affected by Block Island). Long Island Sound to the west provides a slightly longer fetch than from the east. Bathymetry affects the nearshore wave climate, primarily through an offshore trough (the shoreward extension of the Block Canyon drainage pattern) and two shallow nearshore shoals directly off the study area. Wave refraction analysis suggests that the offshore bathymetry focuses energy along the shore. The particular zone of maximum convergence varies along the beach, depending on the direction of deepwater wave incidence, however, the nearshore shoals consistently focus energy at specific shoreline points. The greatest convergence region occurs in the center of the beach associated with the shoal area near profile line 3.

Man has had a major impact on the barrier beaches along Rhode Island and the study area is located along the most densely developed section of beach in the Misquamicut region. In fact, beach profile data suggest that beach behavior in this area may be frequently altered through beach fill operations. Unfortunately, detailed documentation quantifying such operations is not available. The construction of the Winnepaug jetties has also influenced beach behavior, affecting longshore transport in the immediate vicinity of profile lines 1 and 2.

Beach profiles show significant changes over a variety of time scales. Long-term (greater than 1 year) beach changes are evident, predominantly along profile lines 1,2,3,7, and 8 which all show net accretion. This accretion, in part, may mirror eastward longshore transport into the area. Little sand leaves the system because of trapping by the jetties at Winnepaug Inlet, and shadowing of waves approaching from the east. The addition of sand fill in this heavily populated area of the beach may also be a significant contributing factor to the overall accretion.

Seasonal changes in the beach are evident in some years responding to the seasonal variability in storm statistics. In the earlier years of the program, however, the seasonal pattern is obscured by storm events which are more evenly distributed throughout the year. The magnitude of yearly beach changes is about 10 percent (by volume) of that along open ocean beaches such as Cape Cod, Massachusetts.

Higher frequency beach changes occur typically in response to storms. An analysis of beach response to storms shows that the average above MSL volume changes for moderate storms ranges from 5 to 10 cubic meters per meter of beach. Compared to open ocean beaches on other coasts, this is a relatively small storm loss (Cape Cod, about 50 cubic meters per meter). The beaches respond to a number of different types of storms and storm tracks in much the same manner. The greatest amount of erosion associated with storms tends to concentrate near the center of the beach, which most likely results from the wave focusing caused by offshore bathymetric features.

Although some accumulation of sand transported by wind has been reported (U.S. Army, NED, 1957), direct wind effects play a negligible role in beach modifications along Misquamicut Beach. Some offshore sand transport caused by wind may occur near profile lines 1 and 2, but overall, it has a negligible influence. The generation of local waves by wind, specifically when winds are

47

from the west, must play a more important role in beach changes than does direct wind transport.

Visual wave observations support a net longshore sand transport from east to west along this section of beach. Using rough, averaged values of observed wave statistics, a maximum net longshore sand transport rate of 30,000 cubic meters per meter per year appears reasonable for this section of coastline. This, of coarse, is a potential transport rate, subject to availability of sediment.

LITERATURE CITED

ALLEN, E.S., "The Wind That Shook the World," Little & Brown, 1976.

AUBREY, D.G., "Seasonal Patterns of Onshore/Offshore Sediment Movement," *Journal of Geophysical Research*, Vo. 84, No. C10, Oct. 1979, pp 6347-6354.

CODDINGTON, W.J., "Relationship Between Dynamic Nearshore Processes and Beach Changes of NapaWee Point Beach, RI," unpublished Masters Thesis, University of Rhode Island, 1976.

COOK, D.O., "Nearshore Bedform Patterns Along Rhode Island from Side Scan Sonar Survey - Discussion," *Journal of Sedimentary Petrology*, submitted 1981.

DEWALL, A.E., "Beach Changes at Westhampton Beach, New York, 1962-73," MR 79-5, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA, August 1979.

DILLON, W.P., "Submergence Effects on a Rhode Island Barrier and Lagoon and Inferences on Migrations of Barriers," *Journal of Geology*, 1970, pp 94-106.

DOBSON, R.S., "Some Applications of a Digital Computer to Hydraulic Engineers' Problems," TP-80, Stanford University, Department of Civil Engineering, Palo Alto, CA, 1967.

EVERTS, C.H., "Beach Profile Changes on Western Long Island," *Coastal Geomorphology*, Ch. 13, State University of New York, Binghamton, NY, 1973, pp. 279-301.

GALVIN, C.J., "CERC Beach Evaluation Program: Background," U.S. Army Corps of Engineers, Coastal Engineering Research Center, Washington, DC (unpublished), 1969.

GAUTIE, S., "Geomorphology of Southern Rhode Island Shoreline in Relation to Erosion and Accression Characteristics," unpublished Masters Thesis, University of Rhode Island, Department of Geology, 1977.

HAGSTROM, E.L., "Granulometric Analysis of Foreshore Sediments; South Shore in Rhode Island," unpublished Masters Thesis, University of Rhode Island, Department of Geology, 1978.

HICKS, S. and CROSBY, J.E., "Trends and Variability of Yearly Mean Sea Level," NOAA Technical Memorandum NOS 13, NOAA, NOS, Rockville, MD, 1974.

LORENZ, E.N., "Empirical Orthogonal Functions and Statistical Weather Prediction," Report No. 1, Massachusetts Institute of Technology, Cambridge, MA, 1959.

MCMASTER, R.L., "Minerology as an Indicator of Beach Sand Movement Along Rhode Island Shore," *Journal of Sedimentary Petrology*, Vol. 30, 1960, pp. 404-413.

MCMASTER, R.L., "Selected Surveying of Selected Block Island Sound Beaches in Washington County, Rhode Island, 1961-1972," University of Rhode Island, unpublished report, 4 volumes, 1973.

MILLER, M.C., "Beach Changes at Holden Beach, North Carolina, 1970-74," MR 81- , U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA, 1982.

MILLER, M.C. and AUBREY, D.G., "Beach Changes on Eastern Cape Code, Massachusetts From Newcomb Hollow to Nauset Inlet, 1970-74" (in press), U.S. Army, Corps of Engineers, Coastal Engineering Re: ·rch Center, Fort Belvoir, VA (in preparation, 1982).

MILLER, M.C., AUBREY, D.G., and KARPEN, J., "Beach Changes at Long Beach Island, New Jersey, 1962-73," U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1980, p. 289.

MORANG, A., and MCMASTER, R.L., "Nearshore Bedform Patterns Along Rhode Island from Side Scan Sonar Surveys," *Journal of Sedimentary Petrology*, Vol. 50, 1980, pp. 831-840.

PERMANENT SERVICE FOR MEAN SEA LEVEL, "Monthly and Annual Mean Height of Sea Level," Natural Environmental Research Council, United Kingdom, Vol. II, 1977.

RAYTHEON CORPORATION, "Charlestown Hydrographic Study April 1974 through April 1975," Raytheon Corp., Oceanographic and Environmental Sciences, Portsmouth, RI, 1975.

RAYTHEON CORPORATION, "Amendment to Charlestown Hydrographic Study, April 1974-75," Raytheon Corp., Oceanographic and Environmental Sciences, Portsmouth, RI, Sept. 1979.

REGAN, D.R., "An Aerial Photogrammetric Survey of Long Term Shoreline Changes, Southern Rhode Island," unpublished Masters Thesis, University of Rhode Island, Department of Geology, 1976.

RESIO, D.T., et al., "Systematic Variations in Offshore Bathymetry," *Journal of Geology*, Vol. 85, Jan. 1977, pp. 105-113.

SAVARD, W.L., "Sediments of Block Island Sound," unpublished Masters Thesis, University of Rhode Island, 1966.

THOMPSON, E.F., "Wave Climate at Selected Locations," TR 77-1, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA, Jan. 1977.

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND, CORPS OF ENGINEERS, BOSTON, "Beach Erosion Control Report on Cooperative Study South Kingston and Westerly, Rhode Island," November 13, 1957. 15 pages plus appendices.

UNIVERSITY OF RHODE ISLAND, "Rhode Island Barrier Beaches, URI Coastal Research Center, Marine Technical Report #4, 1955.

VINCENT, C.L., et al., "Systematic Variations in Barrier Island Topography," *Journal of Geology*, Vol. 84, Sept. 1976, pp. 583-594.

WESTERLY SUN, February 4, 1966, Westerly, RI.

WESTERLY SUN, October 20, 1972, Westerly, RI.

WINANT, E.D., INMAN, D.L., and NORDSTROM, C.E., "Description of Seasonal Beach Changes Using Empirical Eigenfunctions," *Journal of Geophysical Research*, Vol. 80, No. 15, May 1975, pp. 1979-1986.

APPENDIX A.   PROFILE LINE DOCUMENTATION AND PHOTOS

This appendix provides ground photos and survey documentation for
each of the 8 profile lines along the Misquamicut Beach. The horizontal
location of each profile line consists of a monument set by the Coastal
Engineering Research Center (CERC) in 1974. Each monument is established with
reference to local cultural features and with the state plane coordinate system.
Northing and easting are expressed in feet. Vertical control at each profile
line consists of a third-order elevation of the top of the monument with respect
to the National Geodetic Vertical Datum of 1929. Beach profile measurements
were taken along the specified azimuth and extended to level of -0.6 meter MSL.

Black and white ground photos were taken in 1974 at all profile lines
and illustrate the character of the beach at that time.

COUNTRY	TYPE OF MARK	STATION	
U.S.A	Conc. Mon W/Disk	Profile X-1	

LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION
Westerly, R.I	X-1 (0+00) X-1 (2+92)	C.E.R.C.	Sta 0+00 8.67 MSL. Sta 2+92 16.22 MSL

LATITUDE	LONGITUDE	DATUM	DATUM

	(NORTHING)(EASTING) (FT)	(EASTING)(NORTHING) (FT)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
0+00	8996474	427600.82	R.I Lambert	C.E.R.C.

	(NORTHING)(EASTING) (FT)	(EASTING)(NORTHING) (FT)	GRID AND ZONE	DATE	ORDER
2+92	89679.24	427539.57	R.I Lambert	1974	Third

TO OBTAIN	GRID AZIMUTH, ADD	TO THE GEODETIC AZIMUTH
TO OBTAIN	GRID AZ (ADD)(SUB)	TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

CERC PROFILE #1

SKETCH *Not to Scale*

DA FORM **1959** 1 OCT 64   REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE   **DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION** *(TM 5-237)*

A2

Profile 1

A3

COUNTRY	TYPE OF MARK	STATION	
U.S.A	Conc. Mon W/Disk	Profile "P-5"	

LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION
Westerly, R.I.	P-5 (0+00) P-5 (3+12)	C.E.R.C.	0+00 6.49 M(SL) 3+12 15.01 M(SL)

LATITUDE	LONGITUDE	DATUM	DATUM

Sta. 0+00

(NORTHING)(EASTING)	(FT)	(EASTING)(NORTHING)	(FT)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
90042.28		427103.67		R.I. Lambert	C.E.R.C.

Sta. 3+12

(NORTHING)(EASTING)	(FT)	(EASTING)(NORTHING)	(FT)	GRID AND ZONE	DATE	ORDER
89734.54		427155.03		R.I. Lambert	1974	Third

TO OBTAIN	GRID AZIMUTH, ADD	TO THE GEODETIC AZIMUTH
TO OBTAIN	GRID AZ. (ADD)(SUB.)	TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

CERC PROFILE #2

PROFILE LINE LOCATED APPROXIMATELY 500 ft WEST
OF BRIDGE ON Atlantic Ave

SKETCH Not to Scale

DA FORM 1959 1 OCT 64 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE. DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)

A4

Profile 2

A5

COUNTRY U.S.A	TYPE OF MARK Conc Mon W/Disk	STATION Profile " X-2
LOCALITY Westerly, R.I.	STAMPING ON MARK X-2 Sta 0+10.74 Sta -0+30	AGENCY (CAST IN MARKS) C.E.R.C.	ELEVATION 0+10.74 4.44 M.S.L. -0+30 4.05 M.S.L.
LATITUDE	LONGITUDE	DATUM	DATUM

STA
0+10.74
STA
-0+30

(NORTHING)(EASTING) (FT) 89059.86 (M)	(EASTING)(NORTHING) (FT) 422164.92 (M)	GRID AND ZONE R.I. Lambert	ESTABLISHED BY (AGENCY) C.E.RC
(NORTHING)(EASTING) (FT) 89099.23 (M)	(EASTING)(NORTHING) (FT) 422154.45 (M)	GRID AND ZONE R.I. Lambert	DATE 1974	ORDER Third

TO OBTAIN	GRID AZIMUTH, ADD	°	TO THE GEODETIC AZ'MUTH
TO OBTAIN	GRID AZ. (ADD)(SUB.)	°	TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

To Red & White Water Tank

Sta -0+30
U.S. Engr. Disk CERC
Elev. 4.05 M.S.L.
flush w/ground
127°56'00"

Atlantic   47.43'   76.98'   Ave

Pole #185   27.70'   Sta 0+00 Elev. 4.02 MSL   6926'   Pole #184
Pk Nail   26.13'   4.53   6940'   Pk Nail
Concrete   Side walk

Sta 0+10.74
U.S. Engr. Disk CERC
embedded in sidewalk
Elev 4.44 M.S.L

Sta 0+00 is a 1/8 x 1/2 pin
in black top road 6.15' No.
of Curb Elev. 4.02 M.S.L.
R&H 2334 pg 5

Profile Line
N-14° 53' 38" E
S-14° 53' 38" North
165° 06' 22" North

X-2

N

CERC PROFILE #3

PROFILE LINE LOCATED ABOUT 5500 Ft WEST
OF BRIDGE ON ATLANTIC AVE.

SKETCH Not to Scale.

DA FORM 1OCT 64 **1959** REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE. **DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION**
For use of this form, see TM 5-237; the proponent
agency is U.S. Continental Army Command.

A6

Profile 3

A7

COUNTRY U.S.A.	TYPE OF MARK Conc. Mon. W/Disk	STATION Profile # X-3	
LOCALITY Westerly, R.I.	STAMPING ON MARK X-3 Sta 0+24 Sta -0+19.90	AGENCY (CAST IN MARKS) C.E.R.C.	ELEVATION 0+24 4.07 M.S.L. -0+19.90 3.56 M.S.L
LATITUDE	LONGITUDE	DATUM	DATUM

	(NORTHING)(EASTING) (FT)	(EASTING)(NORTHING) (FT)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
0+24	88793.80 (m)	421348.55 (m)	R.I. Lambert	C.E.R.C.
-0+19.9	88836.52 (m)	421338.44 (m)	R.I. Lambert.	DATE 1974 ORDER Third

TO OBTAIN		GRID AZIMUTH, ADD	TO THE GEODETIC AZIMUTH
TO OBTAIN		GRID AZ. (ADD)(SUB.)	TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

CERC PROFILE #4(68)

PROFILE LINE LOCATED ABOUT 6400 FT WEST
OF BRIDGE ON ATLANTIC AVE
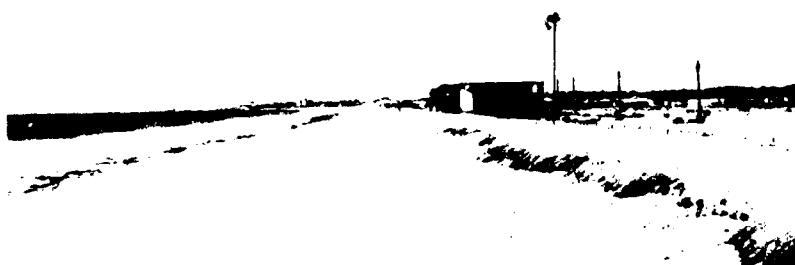
SKETCH Not to Scale

DA FORM 1959 REPLACES DA FORMS 1959 AND 1960 1 FEB 57 WHICH ARE OBSOLETE **DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION**
For use of this form, see TM 5-237; the proponent agency is U.S. Continental Army Command.

A8

Profiles 4,8

COUNTRY U.S.A.	TYPE OF MARK Conc Mon w/Disk	STATION Profile # 11	
LOCALITY Westerly, R.I.	STAMPING ON MARK P-11 Sta 0+60.40 Sta -2+25	AGENCY (CAST IN MARKS) C.E.R.C	ELEVATION 0+60.40 7.79 MSL. -2+25 5.28 MSL.
LATITUDE	LONGITUDE	DATUM	DATUM

	(NORTHING)(EASTING) (FT)	(EASTING)(NORTHING) (FT)	GRID AND ZONE	ESTABLISHED BY AGENCY
0+60.40 Sta	87749.43 (m)	417579.67 (m) R.I. Lambert		C.E.R.C.
-2+25	88030.72 (m)	417531.43 (m) R.I. Lambert		DATE 1974 ORDER Third

TO OBTAIN		GRID AZIMUTH ADD			TO THE GEODETIC AZIMUTH
TO OBTAIN		GRID AZ (ADD)(SUB)			TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

CERC PROFILE #5

PROFILE LINE LOCATED ABOUT 10,400 FT
WEST OF BRIDGE AND ABOUT 2,900 Ft EAST
OF ATLANTIC AVE AND WINNAPAUG RD INTERSECTION

SKETCH Not to Scale

A10

Profile 5

A11

COUNTRY	TYPE OF MARK	STATION		
U.S.A.	Cone Mon W/Disk	Profile #12		
LOCALITY	STAMPING ON MARK P-12	AGENCY (CAST IN MARKS)	ELEVATION	8.11 MSL
Westerly, R.I.	Sta. 0+60.9 Sta -2+23.54	C.E.R.C.	0+60.90 -2+23.54	5.22 MSL
LATITUDE	LONGITUDE	DATUM	DATUM	

	(NORTHING EASTING)	(FT)	(EASTING NORTHING)	(FT)	GRID AND ZONE	ESTABLISHED BY AGENCY
Sta 0+60.90	87406.33		416212.12		R.I. Lambert	C.E.R.C.
	(NORTHING EASTING)	(FT)	(EASTING NORTHING)	(FT)	GRID AND ZONE	DATE	ORDER
Sta -2+23.54	87686.61		416163.62		R.I. Lambert	1974	Third

TO OBTAIN	GRID AZIMUTH, ADD	TO THE GEODETIC AZIMUTH
TO OBTAIN	GRID AZ (ADD)(SUB)	TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

CERC PROFILE #6

PROFILE LINE LOCATED ABOUT
2.1 MILES WEST OF BRIDGE ON
ATLANTIC AVE AND ABOUT
1400 FT EAST OF ATLANTIC
AVE AND NINNAPAUG RD
INTERSECTION

SKETCH   Not to Scale

A12

Profile 6

A13

COUNTRY U.S.A	TYPE OF MARK Conc. Mon. W/Disk	STATION Profile "P-14	
LOCALITY Westerly, RI	STAMPING ON MARK Sta -1+39.80 Sta P-14 Offset -0+97.93	AGENCY (CAST IN MARKS) C.E.R.C	ELEVATION -1+39.80 8.20 MSL -0+97.93 8.26 MSL
LATITUDE	LONGITUDE	DATUM	DATUM

-1+39.80
Sta offs
P-14

(NORTHING)(EASTING) (FT) 86447.52	(EASTING)(NORTHING) (FT) 412197.85	GRID AND ZONE RI Lambert	ESTABLISHED BY (AGENCY) C.E.R.C.

Sta
-0+97.93

(NORTHING)(EASTING) (FT) 86406.20	(EASTING)(NORTHING) (FT) 412204.60	GRID AND ZONE RI Lambert	DATE 1974	ORDER Third

TO OBTAIN	GRID AZIMUTH, ADD	TO THE GEODETIC AZIMUTH
TO OBTAIN	GRID AZ (ADD)(SUB)	TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

CERC PROFILE #7

PROFILE LINE LOCATED ABOUT
3 MILES WEST OF BRIDGE ON
ATLANTIC AVE AND ABOUT
2700 Ft WEST OF ATLANTIC
AVE AND WINNAPAUG RD IN-
TERSECTION

DA FORM 1OCT 64 **1959** REPLACES DA FORMS 1959 AND 1960, 1 FEB 57 WHICH ARE OBSOLETE   **DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION** (TM 5-237)

A14

Profile 7

A15

END

FILMED

3-85

DTIC